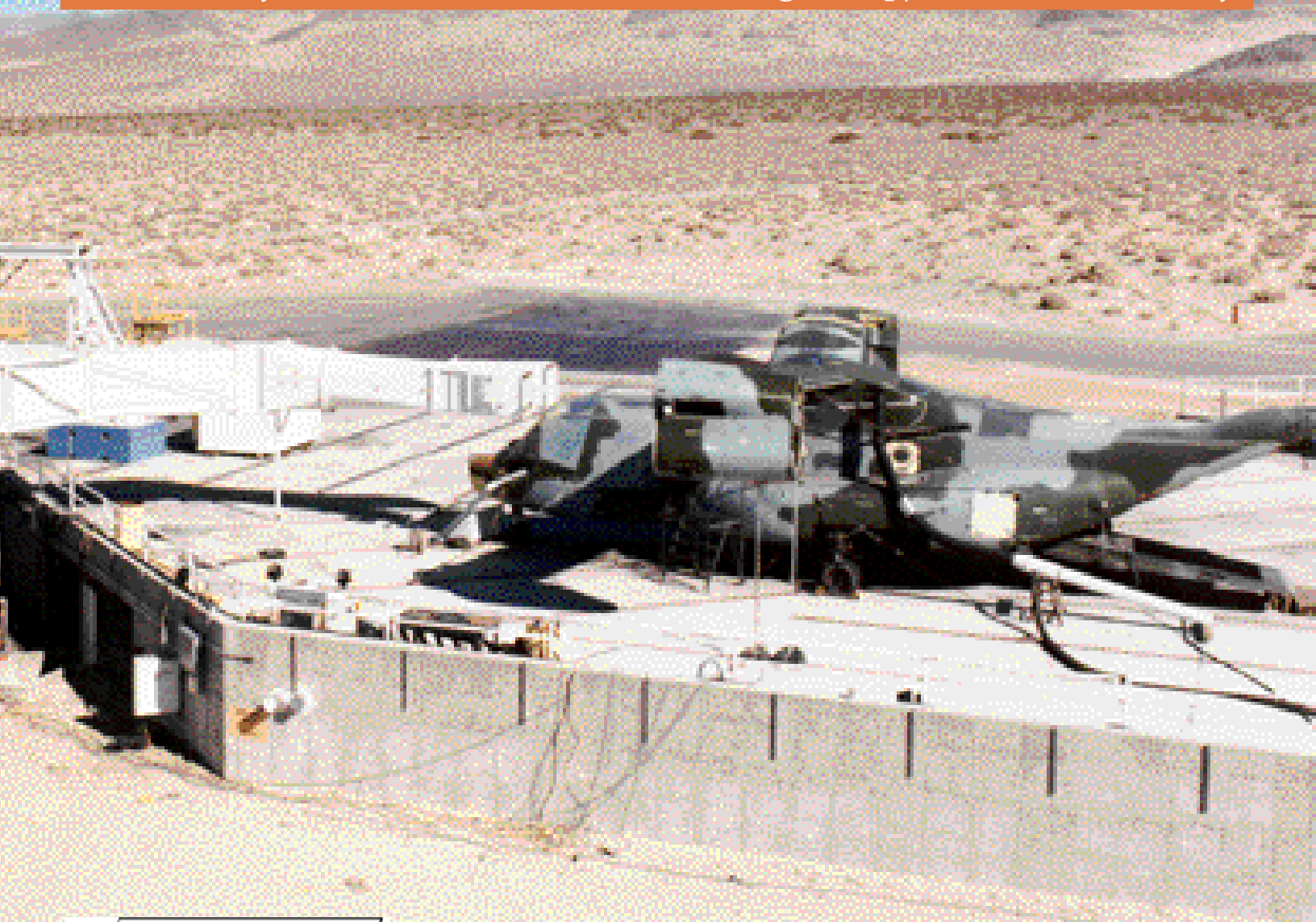


AIRCRAFT SURVIVABILITY

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SPRING 98
Vulnerability Reduction

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Director's Notes

Mr. Joseph P. Jolley

The theme of this issue is Vulnerability Reduction. We're taking the opportunity to share versions of selected presentations from the National Defense Industrial Association's (NDIA) Symposium titled, "Enhancing Aircraft Survivability — A Vulnerability Perspective," conducted October 21-23, 1997, at Monterey, California.

We begin with two introductory articles. The first is authored by the Symposium Chairman, Mr. John Vice, in which he describes the overall proceedings. For the second article, we're very pleased to have RADM Robert H. Gormley, USN Retired, contributing to the Newsletter. He shares his views and insights in his article interestingly titled, "Vulnerability Reduction Deserves Some Respect." RADM Gormley is Executive Board Chairman of the NDIA Combat Survivability Division. The remaining articles were adapted from symposium presentations on various subjects related to Vulnerability Reduction.

Also in this issue is a "current events" article relating successful employment of the V-22 aircraft gas generator fire extinguishing system against an outboard wing fire which occurred while the aircraft was on the ground. The cover photograph shows the setup for the V-22 mid-wing fire suppression test at the Navy Weapons Survivability Laboratory, China Lake.

Another article of general interest describes the testimony given during the National Transportation Safety Board's public hearing into the crash of TWA 800. The hearing was conducted December 8 to 12, 1997, in Baltimore, Maryland. One of the six panels of expert witnesses addressed the issue of fuel tank flammability reduction.

The JTCCG/AS Central Office would like to welcome Ms. Christina Wright of Booz · Allen & Hamilton. Ms. Wright is the new Production Manager of our newsletter, with responsibility for corresponding with the authors, assembling all of the writings, and publishing the final document. The new "look" of the newsletter is also her work. We appreciate having Christina on board as part of the JTCCG/AS Central Office team.

Our special thanks to all of the contributing authors for their time and effort in preparing articles for this issue.

We think you will enjoy reading this issue and find it informative and interesting. Comments and suggestions are welcome.

NDIA Holds Annual Aircraft Survivability Symposium

by Mr. John M. Vice

From October 21 to 23, 1997, the NDIA Combat Survivability Division held its annual survivability symposium at the Naval Postgraduate School in Monterey, California. The symposium was entitled "Enhancing Aircraft Survivability — A Vulnerability Perspective," and its theme was "Meeting Survivability and Safety Challenges for the 21st Century." More than 235 representatives from industry, government and academia met to exchange information and advance ideas on vulnerability reduction designs and technologies, and enhancing wartime survivability and peacetime safety. Presentations by senior executives and policy makers, technical papers, panel discussions and poster papers were used as media for information transfer.

The Combat Survivability Division's mission is to advance the concept of survivability as an essential element of overall combat mission effectiveness. The symposium was designed to increase awareness and foster technology interchange across the DoD, FAA, and commercial aviation. A wide range of organizations cooperated with the Combat Survivability Division in presenting the symposium. These organizations were the Aerospace Industries Association (AIA), Airline Pilots Association (ALPA), American Helicopter Society (AHS), American Institute of Aeronautics and Astronautics (AIAA); Federal Aviation Administration (FAA); Joint Strike Fighter Program (JSF); JTCG/AS; Naval Air Systems Command; National Defense Transportation Association (NDTA); and Army Aviation Research, Development, and Engineering Center.

In line with the theme, dual keynote addresses were presented on enhancing safety and reducing vulnerability. The Honorable John J. Goglia, a member of the National Transportation Board, Washington, DC, spoke to the attendees about "Enhancing Safety: Challenges for Commercial Aviation." Mr. Goglia brings decades of relevant, practical experience to his present position. From a military perspective, Vice Admiral William C. Bowes, USN (Ret.), discussed "Vulnerability Reduction: Critical for Today and Tomorrow." Admiral Bowes, now a Senior Vice

President with Hughes Aircraft Company, El Segundo, CA, has long been a survivability supporter holding numerous Navy staff and command positions. For several years he provided oversight of the JTCG/AS as Chairman, Joint Aeronautical Commanders Group.

Five sessions of presentations and panels along with a poster session, promoted technical information exchanges. Session 1 provided Perspectives on Operational Requirements and Vulnerability Reduction. Senior executives from the Office of the Secretary of Defense, Army, Navy, Marine Corps, Air Force, DoD Operational Test and Evaluation, and FAA discussed the session topic from their organization's perspective and answered questions from the symposium attendees during a panel session. Session 2 addressed "Transport Aircraft: More Safe and Less Vulnerable." The FAA and DoD were highlighted. Session 3, which was a classified session, served as a forum for discussions on "Hit Avoidance Versus Damage Tolerance: Determining the Right Survivability Balance." Threats applicable to civil and military aviation were outlined as part of this session.

Sessions 4, "Advanced Technology: Key to Vulnerability Reduction," presented available and potential safety enhancement and vulnerability reduction technologies. Session 5 discussed applications of these technologies in the latest acquisition programs as part of examining "Affordable/Survivable Aircraft: A Design Challenge." Poster papers and exhibits, available to the symposium attendees throughout the meeting, covered a wide range of technologies, methodologies, capabilities and programs appropriate to the symposium theme.

Many of the symposium presentations are available from the Defense Technical Information Center's World Wide Web site Home Page at www.dtic.mil/stinet. Click on "Special Collections." The next annual NDIA Combat Survivability Division symposium will be held in August 1998. It will address the synergism between low observables and electronic warfare. For additional information contact NDIA at (703) 522-1820.

Mr. Vice is Manager, Dayton Operations for Skyward, Ltd. He received a B.S. degree with honors in Aeronautical Engineering from the University of Wyoming. He also received an M.S. degree in Aerospace-Mechanical Engineering from the Air Force Institute of Technology. He may be reached at 937-427-4261

RADM Robert H. Gormley USN, (Ret), is Chairman of the Combat Survivability Division of the National Defense Industrial Association (NDIA), formerly ADPA / NSIA. He is also President of The Oceanus Company and resides at Menlo Park, California. He may be reached at 650-854-8155.

RADM Gormley at the 1997 NDIA Symposium.

Vulnerability Reduction Deserves Some Respect

by RADM Robert H. Gormley, USN Retired

The JTCC/AS has chosen wisely to devote this issue of Aircraft Survivability to vulnerability reduction technology. The Combat Survivability Division of the National Defense Industrial Association (NDIA) certainly endorses the theme of this edition of the newsletter since we believe aircraft vulnerability reduction has not received sufficient attention in recent years. For this reason, the program for our October 1997 symposium was structured to shed light in this darkening vulnerability "corner" — to see how technological advancements might contribute to enhancing the survivability of both military and civil aircraft.

Illuminating this subject is both topical and highly appropriate on several counts. First, the defense budget continues to be tight and the impact of past decisions to close facilities and terminate programs has yet to be felt fully at working levels, in both industry and government. Hopes aside, there is really little prospect for any fiscal relief on the horizon. Indeed, some very tough decisions regarding major procurements and force levels have been deferred, but when made, as they certainly must be at some point, the pressure on dollars and programs will intensify. As a consequence, advocates for any program or area of endeavor — for example, survivability and its vulnerability reduction element — must have in hand a plan for projects that are seen as relevant and essential. Most importantly, supporting analyses and data must be readied in advance, and advocates must be able to present convincing cases for their projects to those controlling the dollars. Adopting a passive stance and counting on past accomplishments to ensure continuation of a project or activity will, in my view, likely lead to it receiving the death sentence.

In the survivability field, fiscal constraints can lead to a hyper-focus on susceptibility reduction since hit avoidance is without question the first thing one should do to enhance combat survivability. So, the logic might then go, let's not attempt to improve damage resistance and damage tolerance of new

air platforms. Or alternatively, why not relax vulnerability requirements in order to save on development and procurement costs? I urge caution here, particularly in the case of manned aircraft.

It seems to me that those who determine aircraft requirements and characteristics would do well to avoid being too quickly dismissive of vulnerability considerations. They need to look carefully at the full range of possible tactical employment scenarios for proposed new aircraft, giving weight to the historical combat usage record of earlier planes. And before making a final decision on aircraft characteristics, into which the affordability factor must clearly weigh, requirements and acquisition officials should ask themselves two key questions relating to survivability: "If hit, do we really want this new bird to be more likely to be lost than the plane it is to replace?" And, "Is there a need for it to be less vulnerable than the predecessor system?"

These questions need to be asked and answered soon in the case of the Joint Strike Fighter (JSF), which is the only new tactical fighter program on the horizon and potentially a very large one in numbers of aircraft and amount of procurement dollars. Here, a way must be found to assure operators, acquisition decision officials, and the survivability technical community that the design finally selected for Engineering and Manufacturing Development (EMD) will be less vulnerable, or at least not more vulnerable, than those aircraft it will replace — the F-16, AV-8, and F/A-18. The last is clearly the least vulnerable of the lot and, thus, it may not be unreasonable to expect the JSF winner, as a next generation system, to be less vulnerable than the F/A-18E/F.

Among the issues bearing on vulnerability are the increasing inter-dependency of aircraft subsystems, which was discussed at the NDIA symposium, as well as the challenges imposed by the JSF's single-engine design. One way to get the answers is to conduct a comprehensive vulnerability analysis of the two JSF candidates which compares each to the other and to the F-16, AV-8, F/A-18E/F, and possibly the F-22. This kind of effort was undertaken several years ago at a time of

intense dialogue between the Office of the Secretary of Defense (OSD) and the Air Force on close air support aircraft requirements. Here, at the direction of OSD, the A-10, AV-8, F-16, F/A-18, A-7, and respective growth variants, were subjected to a thorough analysis by industry-government teams employing similar methodologies and looking at individual aircraft to about the same degree of detail. But notwithstanding the approach taken to get the answers about JSF vulnerability, the Secretary of Defense and potential combat operators need to know how the design selected for EMD and production stacks up in comparison with the planes it will replace.

Overall, the aircraft survivability community, especially those who deal with vulnerability, would do well to adopt a more active stance and prepare for the increasingly competitive period that lies ahead. This calls for: (1) establishing close relations with key offices in the opera-

tional and acquisition chains; (2) fostering and exercising strong community leadership; (3) identifying concepts and technologies that are clearly worth pursuing; (4) developing better ways of "marketing" new ideas and any need to continue existing projects said to be essential; and (5) improving cooperation between agencies both within and outside the Defense Department. In sum, this is not a time for resting on one's oars since at issue is the very survivability of the survivability community and discipline as you have come to know them.

1998 NDIA Combat Survivability Division Awards

by Mr. Dale B. Atkinson

The National Defense Industrial Association (NDIA) Combat Survivability Division recognizes superior achievement in the combat survivability field through two annual awards. We are soliciting your nominations for these awards to be presented at the annual symposium to be held in Monterey, California, in August 1998 which will be jointly sponsored by the Association of Old Crows.

The awards cover the entire spectrum of survivability, including susceptibility reduction, vulnerability reduction, and related modeling and simulation. The Combat Survivability Division Awards Committee screens candidates and recommends honorees to the Executive board for final approval. The criteria for the awards are shown below.

Survivability Leadership Award

This award is presented to an individual who has made significant contributions enhancing combat survivability. The individual selected must have demonstrated outstanding leadership in furthering combat survivability overall or played a significant role in a major aspect of survivability design, program management, research

and development, modeling and simulation, test and evaluation, education, or the development of standards. The emphasis of this award is on demonstrated leadership of a continuing nature.

Survivability Technical Award

This award is presented to an individual who has made a significant technical contribution to any aspect of survivability. It can be presented for either a specific act or contribution, or an exceptional technical performance over a prolonged period. Individuals at any level of experience are eligible for this award.

Nomination forms may be obtained from Michele Bilowich at NDIA headquarters, phone 703-247-2587, fax 703-522-1885, E-mail mbilowich@ndia.org, or Dale Atkinson, phone 703-451-3011, fax 703-451-4278, e-mail dba@erols.com. Nominations are due to NDIA by 15 May 1998. If you have any questions, please contact Ms. Bilowich at NDIA or myself.

CALL FOR NOMINEES

▼ Ray Schillinger
after being pre-
sented The Surviv-
ability Technical
Award at the
1997 NDIA
Combat Surviv-
ability Symposium.

1997 NDIA Combat Survivability Division Awards

by Mr. Joseph P. Jolley

The National Defense Industrial Association (NDIA) Combat Survivability Division recognizes superior performance in the aircraft combat survivability field by presenting two awards each fall at its annual symposium: the Survivability Leadership Award and the Survivability Technical Award. These awards are presented for achievement across the entire spectrum of survivability, including susceptibility reduction, vulnerability reduction, and related modeling and simulation.

During the fall 1997 symposium, "Enhancing Aircraft Survivability-A Vulnerability Perspective," held in Monterey, California, from October 21 to 23, the Survivability Leadership Award was presented to the team composed of **Mr. David Hall** and **Dr. Paul Muessig**, both from the Naval Air Warfare Center at China Lake, California. This award was presented in recognition of their exceptional leadership while directing the Susceptibility Model and Range Test (SMART) project from 1992 to 1996.

The Survivability Technical Award was presented to **Mr. Ray Schillinger** from the Federal Aviation Administration's (FAA) Technical Center in Atlantic City, New Jersey. Mr. Schillinger was recognized for his achievements as technical leader during the recent United States and United Kingdom explosives tests on a B-747 aircraft.

A Lifetime Achievement Award, a special honor not necessarily bestowed annually, was presented for the first time this year. The 1997 recipients were two individuals whose careers were inextricably linked while serving at the Army Ballistic Research Laboratory, Aberdeen, Maryland. The first was awarded to **Mr. Donald Mower** and the second, posthumously, to **Mr. Roland Bernier**. Each gentleman made significant contributions to the aircraft combat survivability discipline, over a 50-year period, in the areas of aircraft vulnerability test and analysis, methodology development, and vulnerability reduction technology development. Both men were active in the Joint Technical Coordinating Group on Aircraft Survivability for many years and were considered valued mentors to many who worked with them. Mrs. Phyllis Bernier accepted the award on behalf of her late husband.



1998 Aircraft Survivability Symposium

*"Countermeasures and Low Observables:
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Reducing Chemical, Biological and Radiological Vulnerability Through Design

by Mr. Gerald J. Burblis

Recent events over the past several years have heightened military organizations' and air vehicle manufacturers' awareness of the potential threat posed by the damaging characteristics of a chemical, biological, and radiological (CBR) contaminated environment. However, only recently have air vehicle developers been required to take this threat under consideration and incorporate specific levels of protection within the air vehicle system design as specified in the contract's weapon system specification.

Although all air vehicle weapon systems are at a risk of encountering a CBR contaminated environment, certain systems must incorporate enhanced protective features to reduce their vulnerability to this threat. In particular, those air vehicles having a primary mission profile that mandates their conducting operations in proximity to a contaminated ground environment, must consider the unique, damaging aspects of this threat. The system design must be capable of effective and sustained operation in a CBR contaminated environment. Based on operational mission requirements, helicopters have a higher probability of repetitively encountering a CBR threat environment.

To address this threat, systems now under development, such as the RAH-66 Comanche helicopter, have been designed from the onset to incorporate enhanced CBR survivability design features in compliance with the RAH-66 Performance Weapon System Specification requirements. Today's military helicopter systems were not designed with specific features to reduce vulnerability against this unique threat. However, based on intelligence data, the emergence of this threat from probable to definite, in future conflicts, has motivated the military into reviewing and assessing current helicopter systems to determine what can be done to reduce their CBR vulnerability.

To accommodate the process of conducting a CBR vulnerability assessment on a new or existing air vehicle system, a methodology has been developed. This methodology focuses on key aspects of the

threat and how various areas of the air vehicle might be affected.

Initially, a CBR vulnerability assessment of the air vehicle design must consider the CBR threat types most likely to be encountered by the system during performance of its primary mission(s). A thorough understanding of the threat's damage causing potential, magnitude of the potential encounter, and the level of material degradation resistance inherent in those materials incorporated in the basic system design. Next, all flight-critical and essential systems and components must be identified, their primary functions and operation understood, their location within the system specified, and their individual material construction defined down to the parts list level. A material screening process is then conducted to identify those materials that are most susceptible to the damaging characteristics of the threat. To facilitate the assessment process, the air vehicle is divided into regions to support independent assessment and phased upgrade efforts, where an upgrade to the total air vehicle might not be feasible because of budget limitations or unit availability.

Once this process has been completed, a series of recommendations can be formulated and offered for reducing vulnerability to the threat in specific components, areas, or entire regions. The CBR threat affects the air vehicle differently than a ballistic, directed energy, or nuclear threat because its effects happen over time, following repeated exposures, rather than by an instantaneous catastrophic failure of a major system. The most potentially damaging effect inflicted from an encounter with the CBR threat is material degradation leading to leakage, pressure loss, navigational instrumentation impairment, and crew incapacitation. Categorizing materials as acceptable to use in the design because of their CBR resistance capability versus materials with very limited CBR resistance, does not provide the design community with the flexibility it needs to produce a system design that must address all attributes, (e.g. performance and weight) not just CBR vulnerability. The CBR assessment process must consider not only the resis-

Mr. Burblis is a senior CBR/Ballistics Survivability Analyst at Sikorsky Aircraft. He received his B.S. in Aerospace Engineering at Northrop Institute of Technology, Inglewood, CA. Mr. Burblis has 30 years aeronautical experience in weapon's integration and foreign weapon threat characteristics. For the past six years he has been performing all Boeing/Sikorsky CBR and ballistic development activities on the RAH-66 Comanche. He may be reached at 203-386-6092.

Mr. Crosthwaite is the director of SURVIAC. He has worked on several technical analyses and test programs involving a wide variety of weapon systems. Mr. Crosthwaite has a M.S. in nuclear physics from Ohio State and is a licensed professional engineer. He serves on the NDIA Combat Survivability Division Executive Board and on the AIAA Survivability Technical Committee. He may be reached at 937-255-4840.

tance of materials but also their location within the system. A potentially susceptible material can be used if it is afforded synergistic protection using a coating located deep within a computer that negates the probability of direct exposure, or being located in an area having overpressurization and protective CBR filtration.

Numerous features can be utilized to provide CBR vulnerability reduction, which can be as simple as applying a protective coating, or as extensive as adding CBR filtration and overpressurization to selected areas of the air vehicle. The primary focus of a CBR vulnerability assessment is to develop design solutions that provide

enhanced protection for crew members, sensitive electronics, and all flight critical systems. In addition, the incorporation of a detection capability to create awareness of an encounter with a CBR threat may limit contamination through avoidance following detection and minimize decontamination efforts.

The CBR vulnerability assessment is an evolutionary trade-off study process. This process identifies, develops, and recommends those features that produce an optimized design, offering the highest level of protection, and stay within the performance, cost, and weight constraints associated with the program.

Aircraft Vulnerability: A Survey of Combat and Peacetime Experience

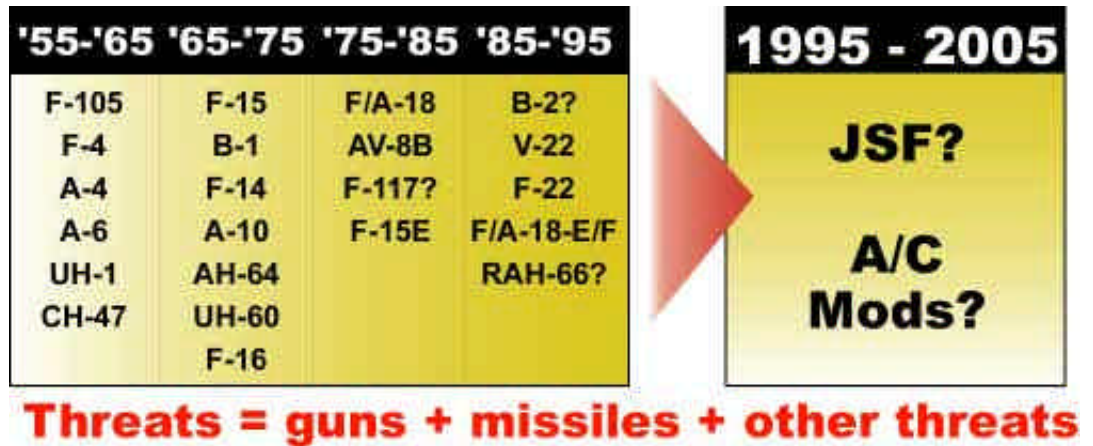
by Mr. Kevin Crosthwaite and Professor Robert E. Ball

Mr. Kevin Crosthwaite, SURVIAC Director, and Distinguished Professor Robert Ball, Naval Postgraduate School provided a historical perspective for measuring vulnerability reduction progress with their respective presentations during the recent

inconsistencies that must be considered when developing new perspectives or projecting into the future.

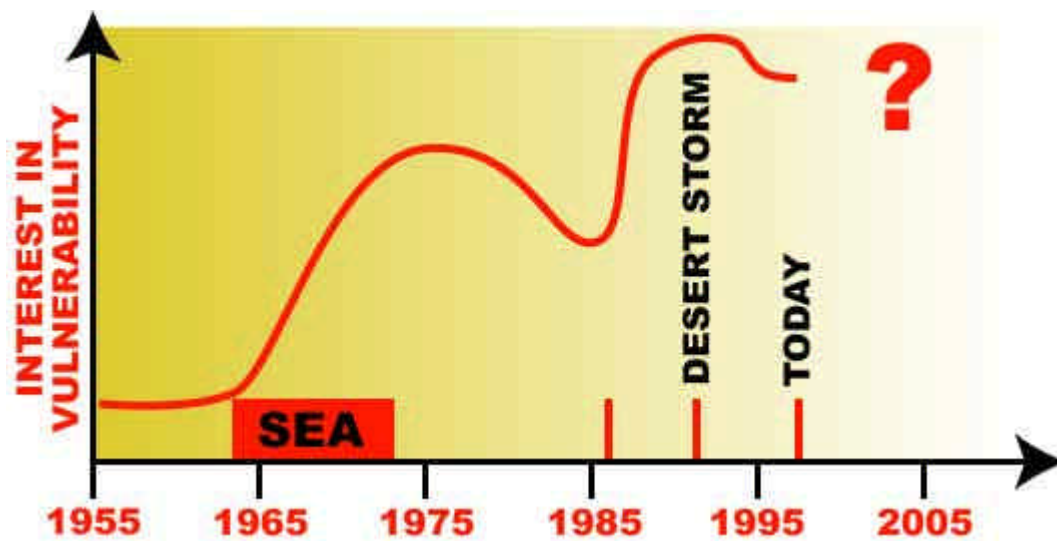
Mr. Crosthwaite did show how the historical data could be exploited to under-

► Figure 1.



NDIA Symposium held on Oct 21 to 23 at Monterey, CA. Mr. Crosthwaite reviewed the basic elements of survivability and susceptibility (probability of hit) and vulnerability (probability of kill given a hit [pk/h]). The symposium was focused on vulnerability reduction. Mr. Crosthwaite described how historical attrition rates have affected operations in previous conflicts. He presented probability of kill given a hit data spanning aircraft losses from World War II through DESERT STORM. The data, which resides at SURVIAC, contains missing elements and

score which aircraft subsystems would most likely be damaged and which would be most critical, potentially leading to aircraft attrition. Knowledge of what constitutes the critical components allows effective focusing of vulnerability reduction efforts on limiting, controlling, or protecting these biggest vulnerability contributors. Mr. Crosthwaite also showed that the historical data on changing the mix of operational missions could explain some of the experienced variations in loss rates or hit rates. Actual combat data substantiates the analyst's intuition that some mis-



sion types are inherently more dangerous from a probability of hit (susceptibility) and a probability of kill given a hit (vulnerability) aspect.

Throughout the briefing it was pointed out that probability of kill given a hit has remained relatively constant during the last 60 years. When averaging overall tactical aircraft types, all threats, and all missions for various conflicts, this average Pk/h is a measure of the aircraft fleet vulnerability to the mix of threats typically faced. Mr. Crosthwaite attributed this key vulnerability measure remaining constant to the efforts of the vulnerability reduction community successfully keeping pace with an ever evolving and more lethal threat. The challenge is to continue to progress and reduce vulnerability to the newer threats.

Dr. Ball built on this historical base of attrition. He focused on a measure he called "interest in vulnerability" (figure 2). Several aircraft design examples were used as evidence of how community interest has waivered over the years. Attrition experienced in SEA increased vulnerability reduction efforts in retrofiting features on the

aircraft operating in SEA and in incorporating features on new aircraft. Furthermore, key legislative action on the Live Fire Test law has promoted interest in vulnerability.

Dr. Ball highlighted the design changes and vulnerability reduction technologies that resulted. He described how these advances in vulnerability reduction technologies and techniques worked to counter the experienced causes of aircraft losses shown by Mr. Crosthwaite. Alternative technologies such as stealth and electronic warfare (EW) that lower susceptibility can compete within the survivability community for interest on vulnerability reduction. Dr. Ball also pointed out that it is essential to maintain a balance of susceptibility reduction and vulnerability reduction. You do not want to get hit; however, you also need to avoid the "cheap kill" if you are hit. This balanced design results in the best overall survivability. The challenge to the community is to maintain and continue to build the interest level in vulnerability reduction by focusing on vulnerability reduction designs that make a positive contribution to aircraft effectiveness.

Mr. Ball received his B.S and M.S. degrees in Civil Engineering from Northwestern University in 1958 and 1959 and the Ph.D. in Structural Mechanics in 1962. He authored "The Fundamentals of Aircraft Combat Survivability Analysis and Design" and established the AIAA Technical Committee on Survivability. In 1996, he was awarded the AIAA Survivability Award. He may be reached at 650-854-8155.

▲ Figure 2.

Ms. Hennigan is a technical writer with the Technical Information Division of the Research and Engineering Competency at the Naval Air Warfare Center Weapons Division, China Lake, California. She holds a B.A. in Literature/Writing with a minor in Scientific Perspectives from the University of California at San Diego. Susan can be reached via e-mail at susan_hennigan@imdgw.chinalake.navy.mil or by telephone at 760-939-3671.

► Figure 1. The V-22 Mid-Wing and Aft Cove Area. The detectors and gas generators marked with an asterisk functioned during the test. (Mid-wing gas generator 7 was disconnected for this particular test setup.)

V-22 SUCCESS STORY: Gas Generator Fire Extinguishing System Technology

by Ms. Susan L. Hennigan

On Sunday, 30 November 1997, a sudden fire occurred in the mid-wing area of a full-scale development (FSD) V-22 aircraft undergoing initial restrained ground testing at the Bell Helicopter-Texton facility in Fort Worth, Texas. The fire was quickly detected and suppressed, proving the efficacy of the gas generator firefighting system aboard the aircraft.

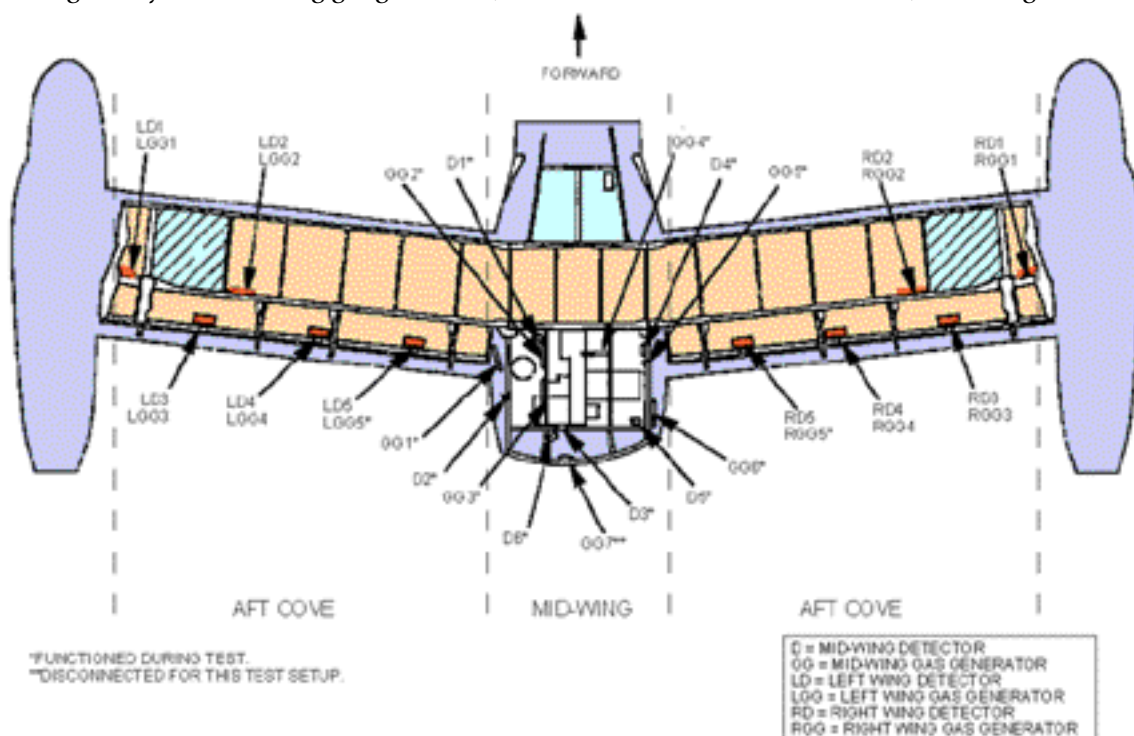
The fire occurred during the engine start-up phase of the ground test and was caused by overheating and failure of the rotor phasing unit (RPU), which had been left in the locked position. (The RPU is used both to fold and unfold the rotor blades and to stow and unstow the wing of the tilt-rotor aircraft.) Connecting lines containing pressurized hydraulic fluid were torn away from the RPU as it sheared off from its mounting, and the overheated unit ignited the fluid spraying within the mid-wing area.

The fire was initially detected by three of the gas generator system's optical detectors located amid the highly cluttered mid-wing area, with a fourth detector indicating the fire shortly thereafter (a total of seven gas generators reside in the mid-wing proper). Detection of the fire by the sensors triggered the expulsion of inert gases by the mid-wing gas generators, and

also, according to system design, by the two gas generators located nearest to the fire zone (on either side) in the adjacent aft cove bay (Figure 1). The gas generator system successfully extinguished the on-board fire, precluding reignition by maintaining an inert atmosphere of carbon dioxide, nitrogen, and water vapor within the mid-wing and aft cove area.

Technology Development

The quick detection and extinguishment of this fire wasn't just "a shot in the dark." In fact, China Lake has been involved with gas generator technology since the mid nineteen-eighties (see "Flame Suppressing Gas Generators," by Dr. Russell Reed, Jr. and Vicki L. Brady in the Fall 1994 issue of Aircraft Survivability). Since that time, numerous test series have been conducted by Survivability Division (Code 418000D) personnel at China Lake's Weapons Survivability Laboratory (WSL) to evaluate gas generator system performance in various applications, including F/A-18E/F engine nacelles and dry bays (tested in fiscal years 1993 through 1997) as well as the V-22 mid-wing and other dry bays (tested in fiscal years 1996 and 1994, respectively). Such extensive testing relies on detailed analyses of potential fire zones within various areas of the aircraft, including assessments



of hot surfaces, fuel sources, ignition sources, and airflow predictions.

V-6-02).

Recently, a team of China Lake survivability engineers; personnel from Northrop Grumman Corporation of El Segundo, California; and employees of Primex Aerospace Company of Redmond, Washington tested a new dry bay fire protection system concept that provides improved protection based on an increase in the duration of agent dispersal and shielding of the gas generators by locating them outside of the protected bay. This cooperative effort made use of a combination of JTTCG V-6-02 and contractor internal research and development (IRAD) funds. A simulated F/A-18E/F dry bay was used to demonstrate concept feasibility. During the demonstration, an HEI was shot into fuel tank 3, followed three seconds later by another HEI shot to fuel tank 4. Both shots penetrated the fuel tank floors and hydraulic lines. A large external fire persisted for several seconds and was extinguished by the gas generator system; no internal fire was observed. This demonstration showed that, despite sustaining multiple HEI hits to its fuel cells, the aircraft was protected adequately and was therefore not destroyed by dry bay fire. As a result, a follow-on test program to continue proof-of-concept testing and system design optimization has been proposed to the Naval Air Combat Survivability Program.

The 30 November V-22 incident marked the first-time employment of the gas generator system in an actual (i.e., not test-induced) aircraft fire. The successful functioning of the system stands as proof positive of gas generator fire suppression technology.

◀ *Figure 2. V-22 Wing Section Simulator During Ballistic Testing at China Lake. (This photo appeared on the cover of the Fall 1994 issue of Aircraft Survivability.)*

▼ *Figure 3. Setup for V-22 Mid-Wing Fire Suppression Test at Weapons Survivability Laboratory, China Lake.*

In the 1996 tests of the V-22, both ground and flight operations were simulated using the aircraft wing and fuselage. Various situations were evaluated, including safety fires (started when leaking flammable liquids ignite) and combat-type ballistic fires resulting from impact by high-speed projectiles. The promising results of these gas generator tests led to system optimization and approval for gas generator use in the V-22 mid-wing application.

Technology Advancement

In 1996 and 1997, the Joint Technical Coordinating Group on Aircraft Survivability (JTTCG/AS) funded the development of propellant formulations for Advanced Gas Generator Technology (Project Number V-6-10). Several combinations of high-efficiency propellant and active chemical agents are under consideration to produce an effective Halon-replacement fire suppression agent. The potential payoff of this project is a new damage mitigation and fire suppression technology that offers substantial benefits in cost, logistics, size, and weight savings. Burn rate tests were conducted by China Lake's Combustion Research Section (Code 4B3100D), and preparation of propellant samples for nacelle protection testing is under way. Full-scale testing of advanced prototypes will be conducted at the Air Force Research Laboratory at Wright-Patterson Air Force Base, Ohio, under JTTCG/AS Next Generation Halon Replacement (Project Number



Mr. Hall is Chief Analyst of the NAWCWPNS Survivability Division; Co-Director of the Joint Accreditation Support Activity (JASA); Chairman of the Methodology Subgroup of JTCG/AS; JSF Survivability IPT Analysis & Modeling Lead; and Chairman of the NAWCWPNS Analysis Resources Science and Technology Network. He may be reached at 760-927-1297.

Integrated Survivability Assessment: Measuring the Balance

by Mr. David H. Hall

A consistent, tri-service approach to Integrated Survivability Assessment (ISA) is needed to support system acquisition within the DoD. A consistent process, applied across all services, would provide needed inputs to the Cost As Independent Variable (CAIV) process being used in DoD. Without this ISA process, the DoD can neither adequately assess nor evaluate design tradeoffs for survivability.¹

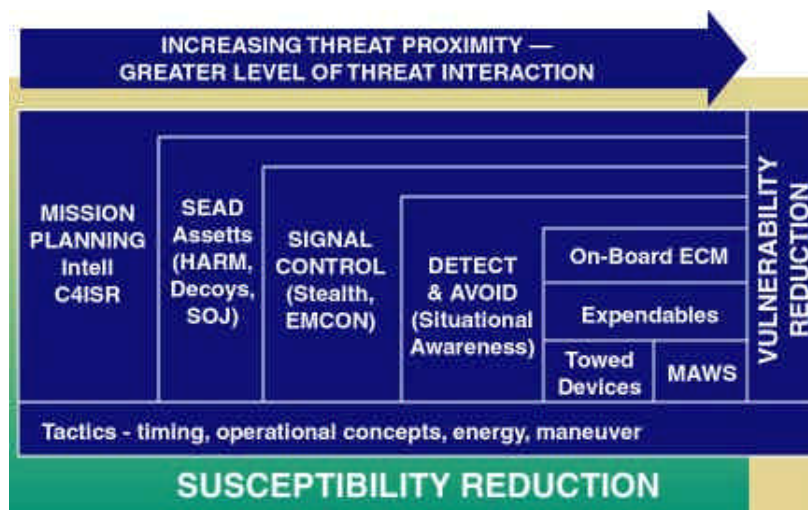
Survivability is a key design element for airborne weapons systems. Over the last several years, reliance has been placed increasingly on the use of models and simulations (M&S) to develop survivability requirements, to evaluate design trade-offs, to determine specification compliance, and for training. This trend toward using M&S is accelerating because of fiscal and other constraints. Models being used earlier in the development cycle are having greater impact. Without an ability to perform a systems engineering approach to design through these models and simulations, the services cannot reach a high performance, low risk, and low cost design. The analyses that support system design, test and evaluation (T&E) and training must be realistic in a mission context, credible and accepted by the joint community.

followed by Suppression of Enemy Defenses (SEAD), where appropriate, with hard and soft kill systems. Once a vehicle has encountered a threat, its own intrinsic characteristics and subsystems come into play, including signatures, countermeasures (active and passive), situational awareness, and tactics. If all these system characteristics are unsuccessful in avoiding a hit by a threat, the vulnerability reduction features designed into the system come into play to ensure that it can withstand that hit sufficiently to at least return to base, or allow the crew to egress safely.

To develop a systems approach to the design of air vehicles for survivability, a standard methodology must be in hand. This methodology must allow for trade-offs among various aspects of survivability in an overall mission survivability context. The lack of a standardized methodology across the services has resulted in system acquisition programs coming before Defense Acquisition Board (DAB) reviews with different approaches to analyzing system survivability, yielding inconsistent or contradictory results. This is partly attributed to a lack of standardization and partly attributed to unfulfilled tool development requirements. However, it is primarily attributed to a lack of a standard approach for integrating the standard tools used in the joint survivability community.

An integrated mission level survivability assessment capability will allow for tradeoffs among all aspects of survivability design, including the effects of off board assets (support aircraft, such as suppression of enemy air defenses assets, standoff jammers, fighter support, and decoys) as well as all on-board assets. With-

out accounting for these contributing factors, a balanced design for survivability cannot be achieved. This capability should reside in current and ongoing on joint service organizations, such as the JTCG/AS and the Survivability/Vulnerability Information Analysis Center (SURVIAC).



Survivability encompasses many aspects of combat (Figure 1), starting with mission planning and Command, Control, Computers, Communications, Intelligence, Surveillance, and Reconnaissance (C4ISR), to minimize the planned interactions with potential threat systems. This process is

► Figure 1.
The Survivability Spectrum

To address this ISA issue, the JTCG/AS and Air Force Operational Test and Evaluation Center at Kirtland (AFG), Albuquerque, NM in May 1997 presented a workshop to evaluate DoD customer needs for an ISA capability, and the potential for ongoing initiatives to satisfy those needs. There was significant participation from all service operational testing organizations, Director Operational Test and Evaluation (DOT&E), and industry, and the system development community in all three services and DoD. Considerable discussion was held regarding service and industry needs for an ISA capability, and the ability of Joint Modeling and Simulation System (J-MASS), High-Level Architecture (HLA) and other ongoing programs to meet those needs.

The operational testing community is focused on those threat systems available to test against. The developmental test community and DOT&E, however, are focused on mission-level assessments that will support evaluations of the military value of systems. This means that between these two communities is a basic difference in emphasis for survivability assessment requirements. This difference is derived from the various levels of understanding about the threat for current and emerging weapons systems and for those systems that are still in the design stage. To support system design tradeoffs, industry needs to not only put survivability into a mission performance context, but also to evaluate detailed technical design alternatives against specific threat systems. Thus, industry requirements for integrated survivability assessment encompass the operational test (OT) and developmental test (DT) communities.

In assessing current capabilities and their expected ability to satisfy the need for integrated survivability assessment, whether it be OT or DT customers, a number of shortfalls were identified. In particular, all the workshop participants expressed concern about the credibility of the M&S used to support the system acquisition process, especially in their ability to evaluate both "system versus system" effects and electronic countermeasures (ECM) effects at a one-on-one engagement level.

For DT customers, especially, there is a perceived need for an iterative analysis process, which would allow the assessment

to be revisited at minimum cost as additional information becomes known about threat system capabilities. Considerable discussion was held regarding the ability of J-MASS and HLA to meet the community's needs in this area. The participants thought that the current Air Force J-MASS program's necessary focus on near-term engagement level assessment (in support of the B-1 DSUP program) meant that few of the DT community's needs would be met by that program in either the near or mid-term.

Concern was expressed that resources that could be applied to ensuring that M&S used in development and T&E were credible and adequate to the job, were instead being focused on developing architectures for future DoD M&S developments. Although participants thought that the goal was laudable long term, there were immediate and near-term needs that were not being met for RDT&E support across the board.

There are cost implications for recoding current capabilities into the Air Force J-MASS architecture as it exists. Concern was expressed that we not lose current capabilities because of lack of resources for recasting them into this new architecture. Because the J-MASS program itself is an architectural development, not a modeling development, more emphasis should be placed on populating this architecture with the required capability to meet customer needs. That effort is not now being adequately addressed.

The JTCG/AS has modified its Methodology Roadmap to include the results and suggestions from the workshop. Emphasis is being placed on M&S credibility and mission-level modeling requirements for survivability assessment. The JTCG/AS has also become a member of the OSD J-MASS implementation team and the Senior Steering Group for J-MASS. This will allow the JTCG/AS to represent the survivability analysis process users to the J-MASS community. Similar relationships are being pursued with the Air Force J-MASS program.

More emphasis was placed on developing requirements for J-MASS architecture and object development, and in planning for transition from existing M&S capabilities to J-MASS based M&S. Greater emphasis was placed on developing standard

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threat missile endgame (fuze, warhead, and vulnerability) methodologies and databases, on mission-level modeling requirements to support integrated assessment, and on M&S credibility verification and validation(V&V).

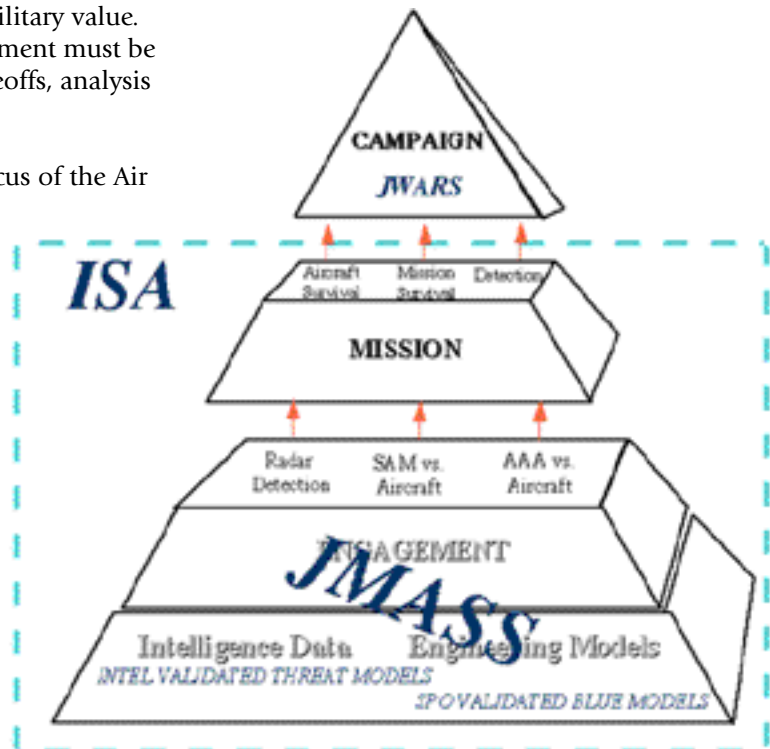
As a result of the workshop, closer ties to the JTCG on munitions effectiveness was seen as a requirement to support user requests for mission effectiveness assessments, which expands the requirements from survivability analysis to include system effectiveness and integration of the two into an assessment of military value. Similarly, links to cost assessment must be made to support design tradeoffs, analysis of alternatives, and CAIV.

Figure 2² illustrates the focus of the Air Force J-MASS program and its relationship to the pyramid of engineering, engagement, mission, and campaign level assessment tools. Air Force J-MASS is focused on engineering and engagement level simulations. The requirements of ISA can leverage the M&S developments accomplished under J-MASS; however, the ISA is focused on integrating analytical requirements and capabilities at the mission, engagement, and engineering levels. ISA provides a consistent, tri-service analysis process for making survivability a key element of systems engineering. This process will use many tools, including M&S, some of which will be developed under J-MASS, some of which whose credibility has been established and maintained by joint service activities, and some of which may be commercially developed.

Survivability is a major design element of air weapons systems acquisition programs. However, an effective systems engineering approach to survivability design is not possible because of the lack of a standard, accepted, ISA process that would examine, in concert, all critical elements of survivability. This capability must be developed and distributed to the entire survivability community in all the services and industry through SURVIAC. This process must leverage on-going service efforts, such as J-MASS and the development of the HLA. This will ensure a

seamless, cost-effective transition from existing mature M&S to any new M&S developed under the J-MASS architecture and/or with HLA interfaces. The only way that this will come about is if the JTCG/AS can have the participation of the entire community in the process: all the services, industry, academia, and OSD.

► Figure 2.
Future M&S Integration



¹ This capability was recommended by the National Research Council study "Live Fire Testing of the F-22"; some specific references in that document include the following.

"Recommendation 6: (Re)examine...the balance of requirements among susceptibility, vulnerability and related performance parameters"

"...it is important to examine vulnerability within the context of overall survivability." "Since survivability is influenced by all three terms (Pd-probability of detection, Ph/d-probability of hit given detection, Pk/h-probability of kill given a hit) the aircraft designer should not make changes to any one of them without considering its effects on the other two."

² This figure was extracted from a J-MASS Industry Day briefing by Col Allen of Air Force Studies and Analysis.

Flight System Integration Effects On Aircraft Vulnerability

by Mr. Bruce Clough

The buzzwords of aircraft procurements are no longer "range," "maneuverability," or even "stealth", but center on the word "cost". If we cannot afford it, we will not build it. New capabilities have to "buy" their way aboard aircraft. In flight systems development, the way we're "buying" our way aboard aircraft is via integration, with reduced size, weight, and equal or better performance as side benefits. However, during this rush to integrate, the effect of our decisions on vulnerability is usually not examined in detail; therefore, we could be leaving ourselves vulnerable without realizing it. The JTCG/AS Vulnerability Reduction Subgroup Flight Systems Committee is taking this challenge seriously and is actively pursuing programs to eliminate vulnerability gaps. This article discusses these integrating technologies and their effects.

Webster's defines "integration" as "to form, coordinate, or blend into a functioning or unified whole." For flight systems this means merging individual functions. The current push in flight systems is integration, not necessarily development of new systems. Studies preceding the current Joint Strike Fighter (JSF) concept demonstration phase show possible benefits realized from integration:

- Reduced weight: 2 to 4 percent reduction in takeoff gross weight
- Reduced size: 20 to 50 cubic foot savings
- Reduced cooling: Avionics heat loads reduced 30 to 50 percent
- Reduced cost: 3 to 4 percent reduction in life cycle cost

These exciting savings have led to a current round of innovative technology integration demonstrations supporting fighter development in the first decade of the next century.

The following paragraphs discuss integrating technologies for flight systems. We will provide a short description of each and explain what makes each useful.

Integrated Flight/Propulsion Control (IFPC)

The ability of the flight control computers and engine control computers to talk to each other has opened exciting capabilities in aircraft control. Thrust vec-

toring, engine stall margin control, thrust reversing, and improved STOVL operation are fallouts of the airframe passing flight condition information to the engine, and the engine instructing the aircraft what it is capable of at any point in the flight envelope. Probably the best example of IFPC is the F-22, using IFPC for attaining its world-class performance characteristics.

"Tailless" Aircraft

If vertical tails could be removed from aircraft, we could significantly reduce its observability and save weight. However, vertical tails are there to maintain directional aircraft stability. For several decades, we have been controlling aircraft that are unstable in pitch; however, with the advent of higher performance computers, we now can relax the directional stability. Programs such as the Air Force Research Laboratory's Innovative Control Effectors (ICE) and the X-36 demonstrate the utility of tailless configurations.

Integrated Flight/Structure Control (IFSC)

Active control of aircraft structures provides benefits in weight reduction, fatigue control, and improved maneuverability. For instance, significant weight is built into a wing to maintain torsional stiffness. If that weight is eliminated, and the aircraft control system is used to compensate for the decreased stiffness, we could save hundreds of pounds per aircraft. The Air Force Research Laboratory, with the assistance of NASA, has a program underway to flight test such a concept in a front line fighter, as well as flight testing other concepts on unmanned reset aircraft.

More Electric Aircraft (MEA)

Current aircraft use a combination of secondary power, electric, hydraulic, and pneumatic for powering aircraft systems. If we could get all of the aircraft systems to use one source of secondary power (i.e., electric), significant aircraft savings, gained by totally eliminating logistical tails for pneumatic and hydraulic system, would be possible. Additional savings are gained by combining the emergency power generation and maintenance functions so an aircraft can be operated on the ground, eliminating ground power carts. Over the last decade, the Air Force Research Labora-

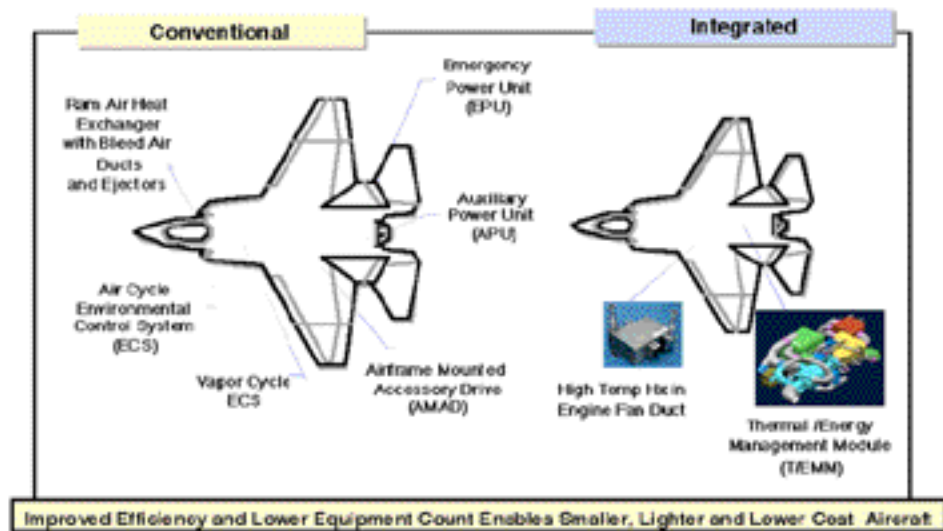
Mr. Clough wears both research and management hats in Advanced Flight Control System Integration for the Air Force Research Laboratory. He leads propulsion integration for the JSF Integrated Flight/Propulsion Control IPT and chairs the Flight Systems Committee of the Vulnerability Reduction Subgroup, JTCG/AS. Mr. Clough received his B.S.E.E. from the University of Akron in 1982 and his M.S.E.E. from the Air Force Institute of Technology in 1985. He may be reached at 937-255-2831.

tory has pioneered MEA, sponsoring numerous ground and several flight demonstrations.

Integrated Thermal Management/ Secondary Power

Current aircraft have a conglomeration of federated systems that handle the secondary power generation and aircraft environmental control. Suppose these could be integrated? Significant reductions in parts count, equipment weight, and volume could be realized. Demonstration of this technology is part of the JSF Integrated Subsystems Technology demonstration. Figure 1 compares a federated versus an integrated system, illustrating the magnitude of total equipment reductions possible.

Thermal/Secondary Power



► Figure 1.
Impact Of Thermal Management/Secondary Power Integration

Prognostics And Health Management (PHM)

With the increased control capability coming from better sensors and processing power comes an ability to predict equipment failures and take compensating measures before failure. Although PHM is extremely useful to, and targeted at logisticians and maintenance troops, PHM can also be used to assess remaining aircraft capability after being hit and to help in aircraft reconfiguration to recover performance.

Vehicle Management System (VMS)

Although the integrating technologies discussed above are powerful, the integration of these integrating functions occurs in the VMS. The VMS enables the synergistic savings of a combination of individual technologies. The VMS has its beginnings in the humble flight control computer, but its control span has grown to a point

where it commands and coordinates all of the aircraft except mission avionics as shown in Figure 2. The VMS concept, which has been proven over the last decade, is being utilized in modern fighters, such as the F-22.

Note that the above technologies are not laboratory curiosities, but cornerstones of new aircraft development. The JSF is counting on many of these integrating technologies to meet aggressive low lifecycle cost goals while maintaining or increasing aircraft performance. Developing these technologies is ongoing, with the technologies coming to fruition within a few years. The integration is being pushed for lifecycle cost and performance benefits, but what effect do they have on vulnerability?

Will integration of flight systems across the aircraft make it more or less vulnerable? One can make arguments in either one's favor:

Pro

Integration reduces the overall computer box count; therefore, it reduces the size and number of potential targets aboard the aircraft. Integration reduces aircraft wiring,

reducing targets and short-circuit possibilities. Integration results in less flammable liquids, whether from elimination of the hydraulic system or avionics cooling loops. Integration allows better damage identification and reconfiguration from the sharing of information across common buses.

Con

Integration forces individual components to become critical for several systems, increasing the severity of failure modes. Integration results in highly coupled, complex systems having unpredictable failure modes; therefore, failure testing cannot determine all conditions that may actually be encountered in battle. Integration results in systems becoming flight critical that were not in the past; thus, the system design based on existing paradigms may not be as good as it should be. Integration results in the mix of critical

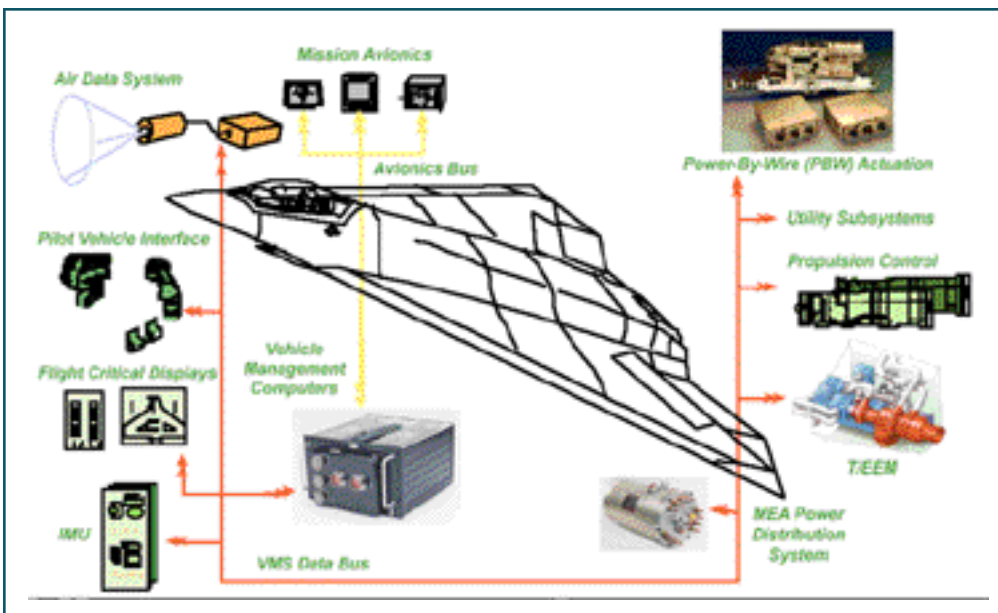
and noncritical functions in the same box, complicating the system's response to failures where it sheds non-critical functions to maintain critical ones. Integration allows reduced strength in other systems that might have been useful under fire. For instance, IFSC results in reduced torsional strength in a wing, which might have been handy given a ballistic hit.

It is recognized that integration has survivability impacts beyond vulnerability. The smaller size, reduced weight, greater payload, better performance, and better situational awareness resulting from integration do reduce susceptibility; however, this article is focusing on the vulnerability impact of the technologies. At a higher level, we are examining the impact to aircraft survivability, into which our current assessments of vulnerability impact feed.

We determine integration's vulnerability impact precisely the same way that we integrate the technologies. First, the effects of the individual technologies are determined, then these individual vulnerabilities are integrated to form the vulnerability of the integrated flight systems. The first step is underway in several areas: More Electric Aircraft Vulnerability Analysis (MELVAN) program, funded by the JTCG/AS, is evaluating the effect of MEA technology on aircraft vulnerability. The JTCG/AS is also funding improved techniques to identify damage in real time and

reconfigure the flight system to account for the damage. The technology developed will be transferred to structures that are also interested in real-time damage identification. Future JTCG/AS programs addressing IFPC, IFSC, and thermal/secondary power are on the books with completion dates supporting JSF (EM&D). Through the JTCG/AS and JSF program offices, the lessons learned in our ongoing programs are being related to the weapon system contractors who will then benefit by our experience.

Aircraft performance increase and cost containment are driving flight system integration. The level of integration over the next few years will lead to savings unheard of previously; however this improvement will come with some impact to aircraft vulnerability. Will this impact be a decreased vulnerability because of the overall reduction in box count, wiring, and elimination of flammable fluids, or will it increase because of increased criticality of the remaining components? Programs are underway to determine this impact and mitigate negative influences because the lifecycle cost benefits of integration will drive its use from now on. We feel confident that the aerospace community is examining the issue, and will develop answers for upcoming aircraft procurements. The question of integration's overall impact on aircraft survivability is an issue for the integrated JTCG/AS vulnerability and susceptibility disciplines.



◀ Figure 2.
Layout Of Typical
Vehicle Manage-
ment System

Mr. Schillinger is a graduate of Embry Riddle Aeronautical University and an Aerospace Engineer with the Office of Aviation Security Research and Development, Aircraft Hardening Program. He may be reached at 609-485-4927.

▼ Photograph of 747 during the test blast.

Boeing 747 Explosive Test

by Mr. Ray Schillinger

In a joint effort conducted on May 17, 1997, the Federal Aviation Administration (FAA) and the British counterpart, Civil Aviation Authority (CAA) conducted a test to study blast effects and feasible vulnerability reduction techniques on a pressurized decommissioned Boeing 747. Specifically studied was the potential application of hardened container or liner technology to mitigate blast effects within the cargo hold of a wide-body commercial aircraft.

Since 1991, FAA Aviation Security Research and Development Service, Aircraft Hardening Program (AHP), and the CAA have shared a mutual interest in commercial aircraft hardening methodologies and techniques to mitigate the potential catastrophic structural or critical system failure attributed to an in-flight explosion. As part of this research, the AHP and CAA jointly acquired a 747-100 test asset to study the effects of explosive devices on wide-body commercial aircraft. Additional key players in the project included the Defense Research Agency, Defense Evaluation and Research Agency (DERA), National Transportation Safety Board, and Naval Research Laboratory.

To maximize the one-of-a-kind test asset and effort, four distinct test objectives were established:

- Conduct a series of vulnerability and lethality tests on a wide-body commercial aircraft using various explosive charge weights, configurations, and locations
- Study the effects of an explosive event occurring in a wide body commercial aircraft cargo hold

- Study and identify potential methods and techniques of enhancing aircraft resistance and survivability to explosives within the aircraft structure
- Identify and study methods and techniques of minimizing the effects of explosives through the use of blast management, hardened luggage containers, and liners.

The test series was conducted at Bruntingthorpe Aerodrome, Leicestershire County, England, under the direct control of DERA. A decommissioned Boeing 747 (previously owned by Air France) was used as a test asset. The 747-100 was built in 1970 and eventually sold for scrap in 1994, with more than 76,000 hours logged on the airframe.

Four equal amounts of explosives, distributed between the forward and aft cargo hold, were to be detonated at the same time. This approach would allow the test activity to maximize the use of the single pressurizable asset. To record four explosives events occurring on one test, a combination of photographic and instrumentation was utilized. The photographic package included still, motion, and high-speed photography. The instrumentation package consisted of 62 gauges that recorded pressure, acceleration, strain, and temperature. The aircraft was equipped with several area and cockpit voice recorders.

Of the four separate shots, the FAA first tested a hardened unibody luggage container (similar in configuration to aluminum luggage containers currently in use on commercial wide body aircraft) made from a material similar to kevlar. The CAA



then tested a hardened liner, made of similar material, that attached directly to the cargo hold bulkhead. Next, the CAA tested an even simpler concept consisting of lining a standard aluminum container with a rigid foam insert. This concept, although unable to completely absorb a blast event, would enable the charge to be further displaced from the fuselage. The fourth shot consisted of a standard aluminum container.

After the aircraft was pressurized to a simulated cruise altitude of an estimated 30,000 to 35,000 feet, all four charges were simultaneously detonated in various locations of the forward and aft cargo holds.

After the blast, it was apparent that the explosive event that occurred within the unprotected container (baseline) in the aft cargo hold caused catastrophic damage to the aircraft. Although further analysis is required, the rigid container concept provided an improved method of reducing the blast forces from the fuselage.

The most significant improvement to blast survivability occurred in the forward

cargo hold, where the hardened container and liner was utilized. At both locations, minimal damage occurred to the fuselage skin adjacent to the blast site.

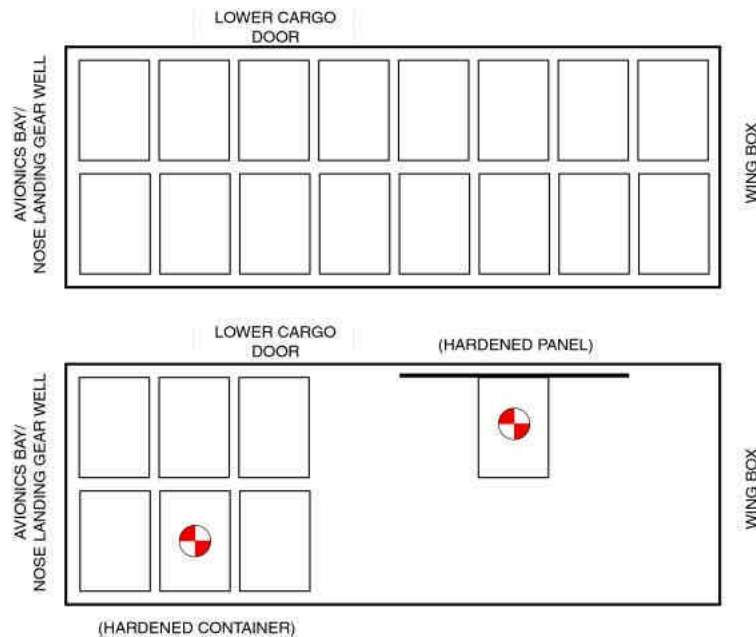
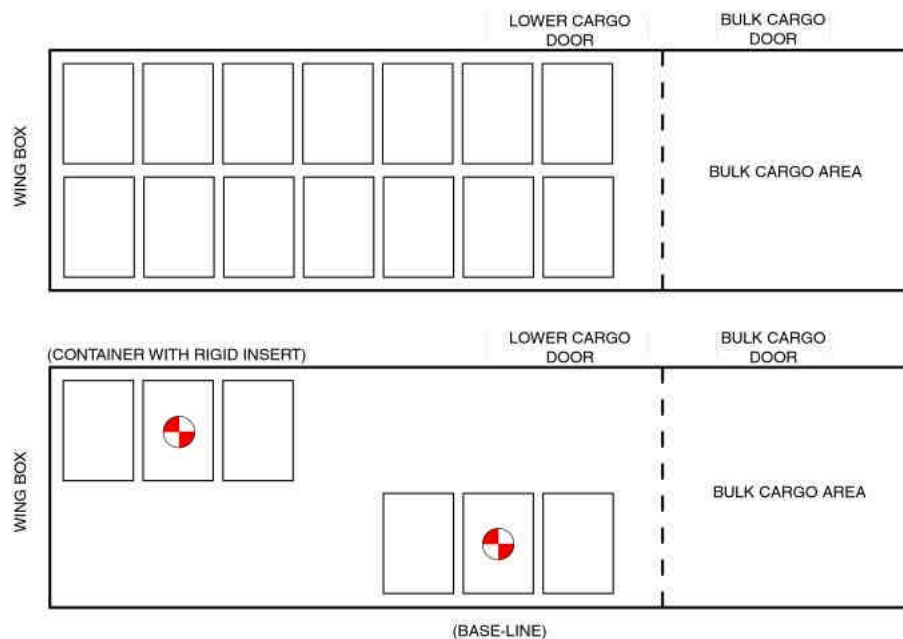


Figure 2
Forward Cargo Hold

Figure 3
Aft Cargo Hold

The FAA intends to study further the successfully tested hardened containers utilizing various technologies. In coordination with the Air Transport Association, the FAA will provide the containers to airlines for operational assessment. Approximately 20 to 50 containers will be deployed and tracked for operational utility, durability, and need and ease of repair.

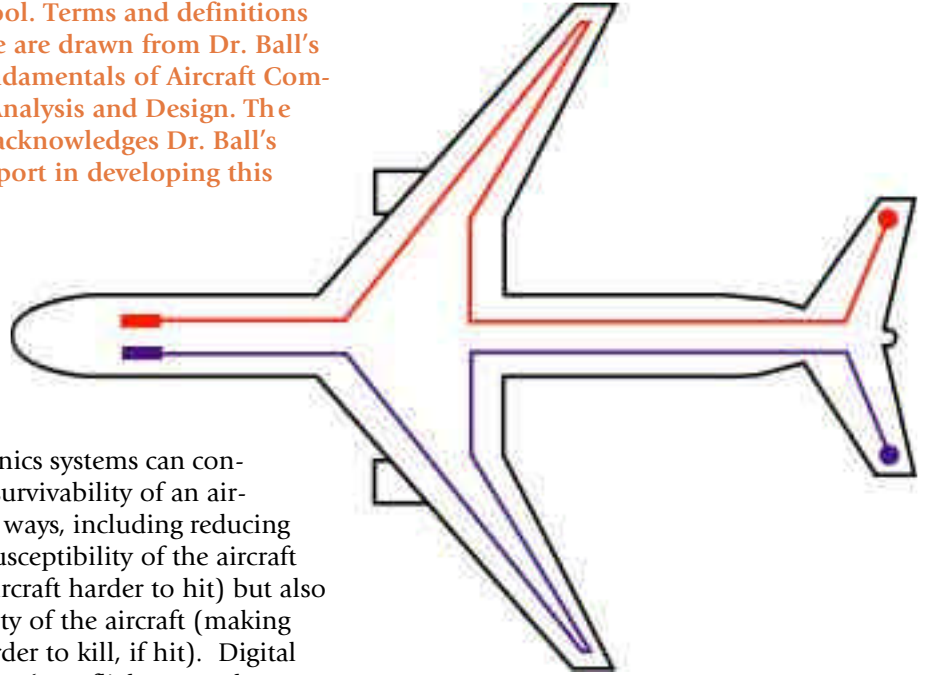


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Designing Digital Avionics Systems for Reduced Vulnerability

by Mr. Wade D. Duym

Author's Note: This article is based on an M.S. thesis written by the author, Wade D. Duym, under the direction of Distinguished Professor Robert E. Ball, Ph.D., at the Naval Postgraduate School. Terms and definitions used in this article are drawn from Dr. Ball's textbook, *The Fundamentals of Aircraft Combat Survivability Analysis and Design*. The author gratefully acknowledges Dr. Ball's guidance and support in developing this article.



Digital avionics systems can contribute to the survivability of an aircraft in several ways, including reducing not only the susceptibility of the aircraft (making the aircraft harder to hit) but also the vulnerability of the aircraft (making the aircraft harder to kill, if hit). Digital avionics systems (e.g., flight control systems, engine control systems, flight displays, and sensor systems) are essential items in modern aircraft, and improving their survivability by designing for reduced vulnerability is a high payoff activity.

Vulnerability reduction is defined as the use of any design technique or equipment to control or reduce the amount of damage or the consequences of damage to the aircraft, when the aircraft is hit by one or more damage mechanisms. The six vulnerability reduction concepts are as follows:

- Component Redundancy (with separation)
- Component location
- Passive damage suppression
- Active damage suppression
- Component shielding
- Component elimination

Each vulnerability reduction concept may be used to improve the survivability of the digital avionics systems. Component redundancy (with separation) refers to the use of multiple devices, parts, or mechanisms to perform a given task. The use of multiple, redundant data buses is an example of actual redundancy using identical

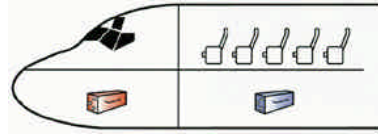
components. The requirement for physical separation of the redundant components is intended to prevent them from being killed by a single event. For example, it would be considered good design practice to route the multiple redundant data buses as far apart from one another as possible, within the constraints of the aircraft structure (Figure 1).

Component location means the choice in the design phase to position a component such that a damage mechanism is less likely to kill the component (Figure 2). Applicable design techniques are as follows:

- Orienting a component's presented area to reduce the likelihood of being hit by a damage mechanism coming from the most probable direction
- Locating noncritical or ballistically hardened components in front of more vulnerable components
- Reducing the presented area of nonredundant components
- Locating components in order to prevent cascading damage.

► Figure 1.

For aircraft that use a central avionics bay, the demands for easy access for maintenance must be traded off against the need for survivability in locating the critical avionics components. For most aircraft, the trend toward component miniaturization aids aircraft survivability by reducing the presented area of critical components, thereby reducing the aircraft's vulnerable area.



absorb the damage mechanisms. The use of armor is the most common example of this technique. Here, the design tradeoff is between the weight of the shielding and the necessary level of ballistic tolerance. Because most avionics devices are not

◀ Figure 2.

Passive damage suppression refers to features that either contain the damage or reduce the effects of the damage when an aircraft encounters a damage mechanism. Applicable design techniques are as follows:

- Damage tolerance
- Ballistic resistance
- Delayed failure
- Fire and explosion suppression
- Fail-safe response.

Techniques available to the avionics designer include the use of less vulnerable materials that are tolerant of the loss of the integrity of the environmental shield and ensuring that components are able to be easily isolated to prevent a “cascade” failure to the system.

Active damage suppression is a technique that employs a sensor or other device to sense the onset of a damage process and activates some mechanism that contains the damage or reduces its effects. A primary example of this type of technique is a fire detection and extinguishing system.

Component shielding is the technique of using coatings or materials that resist or

themselves in hardened housings, this technique is usually applicable to shielding around the avionics bay (see Figure 3).

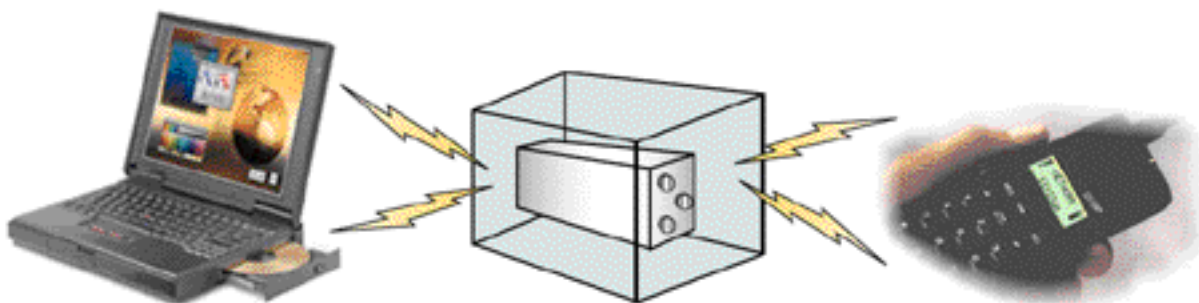
▼ Figure 3.

Component elimination refers to the design choice of either eliminating a component entirely or replacing it with another, less vulnerable, component. An example for an avionics component would be to choose a passively cooled component over one that relies on forced air cooling because this reduces the component's vulnerability to damage if cooling air supplies are lost.

Designing digital avionics systems for reduced vulnerability should be important to the designer for three main reasons:

- Enhance flight safety
- Anticipate and counter possible terrorist threats
- Reduce or minimize military threats.

By considering the six vulnerability reduction concepts during the design stage, the vulnerability of digital avionics systems can be reduced.



Mr. Frankenger has worked in the propulsion field at NAWCWPNS for 12 years, including 8 years in missile propulsion on programs including Tomahawk, Harpoon/SLAM and Advance Air-to-Air Missile. He has worked Engine Vulnerability issues for the past 4 years conducting ballistic tests on turbine engines under JTCG/AS, JLF and LFT efforts. He may be reached at 760-939-3681.

Assessing the Disk Burst Threat

by Mr. Charles E. Frankenger

Naval Air Warfare Center, China Lake, Survivability Division, has recently been investigating the turbine engine disk burst phenomena. Disk burst is described as a rotor failure that results in engine rotor fragments and blade fragments exiting the engine case during engine operating conditions. This phenomenon is a threat to commercial and military aircraft. Uncontained disk failures in military or commercial aircraft are frequently the result of corrosion, material flaws, or maintenance error. In a hostile threat environment, disk burst can be the result of a penetrating ballistic projectile. To address this issue, China Lake has leveraged funding with the DoD and the FAA.

Under DoD funding, China Lake has initiated disk burst testing to identify the first order effects of ballistic penetration of turbine engine disks. Testing conducted on an F404 engine resulted in a spectacular event, which has had a significant effect on understanding the importance of engine vulnerability. Additional testing conducted on the T56, T406, and TF30 engines has yielded somewhat different results. These tests indicate that engines are much less susceptible to disk burst than previously thought. Individual rotating component tests have also been conducted using an open air spin fixture (developed under OSD/LFTE funding). Initial findings again indicate that not all disks burst when penetrated. Current prediction techniques are inadequate, and are no better than flipping a coin. The objective of these activities is to develop a disk burst prediction methodology that can be used by engine designers to develop ballistically tolerant disks in the future. This advancement will also lend itself to the current safety issues in peace time and in the commercial sector.

Under the umbrella of the FAA's Catastrophic Failure Prevention Program, China Lake is conducting the Uncontained Engine Debris Characterization and Mitigation Program. This activity has taken the China Lake team to several uncontained event investigations to collect data to define the uncontained debris size, velocity, and trajectory. General Electric Aircraft Engine Company, Pratt and Whitney, Allison Engine Company, Allied Sig-

nal, Rolls Royce, and Boeing Aircraft Company have also provided historical uncontained event data. This data has been crucial in developing a model of the uncontained engine debris.

Disk failures and uncontained blade failures have been investigated under this program. Uncontained engine failures on average result in 11 holes in the aircraft. Disk failures have a higher number of damages than blade failure events. The average hole size is about 8 x 2 inches on the aircraft fuselage. A debris energy analysis was conducted using the JTCG penetration equations. The analysis was focused on blade fragments, as disk fragment energies are sufficient to pass through most aircraft structure. This analysis provided the key link in understanding the relationship between the holes in the aircraft and the debris that has been found after an uncontained event.

Vulnerability assessment tools (COVART and FASTGEN) have been modified to model an uncontained engine failure. These tools, combined with the debris model, are being evaluated for use in commercial aircraft safety assessments. Future efforts could lead to the use of these tools in the design and certification of new aircraft. Other participants in the FAA's research program include SRI International and Lawrence Livermore National Laboratory (LLNL). SRI is tasked to define and model barrier or mitigation materials developed under DoD Armor programs and LLNL is tasked with defining aluminum and titanium material failure models for use in DYNA3D.

Through collective efforts under DoD and FAA, a clear understanding of the disk burst phenomena and the resulting uncontained debris will be achieved. Tools will be available to engine designers to develop ballistic-tolerant disks, and to aircraft designers to model and mitigate the effects of an uncontained failure. Safer airplane designs will then be available in the future.

Treating Aircraft Vulnerability in Campaign - Level Assessments

by Mr. Hugh Griffis

BACKGROUND

Today, many program offices are required to conduct an "Analysis of Alternatives" (AoA) to justify each program milestone. These AoA activities require a series of analyses at the engineering analysis, one-on-one fly-out, endgame-terminal effects, mission, and campaign levels. Evaluation metrics used in an AoA compare alternative design concepts with the baseline capabilities. Metrics such as blue aircraft losses (survivability) and red aircraft kills (lethality) per sortie continue to be common AoA metrics. Aircraft survivability is directly related to the vulnerability posture of our systems and the capabilities of threat systems. The Hierarchy of Survivability pyramid, figure 1, depicts parametric tests, engineering analysis, and vulnerability analysis as the fundamental foundation of the hierarchy. However, all too often the testing, engineering analysis and vulnerability analysis activities are weakly treated analytically within the AoA.

In the past, vulnerability analysts defined the value of vulnerability with the survivability equation,

$$PS = 1 - PK$$

where PS is the probability of survival and PK is the probability of kill. The survivability equation inadequately describes the value of vulnerability in the context of an AoA. Critical AoA data such as losses and kills per sortie cannot be derived via the survivability equation. Therefore, the survivability engineer within the program office may be unable to define justifiable vulnerability design requirements and may be unable to defend expenditures to achieve design requirements.

These problems occur because vulnerability data has been lacking and historically vulnerability data has been incorrectly used within the Hierarchy of Survivability analysis process. Within each level of modeling the analysts defines a PK. The numerical value and usage of this PK changes within each analysis level. Hence, the term PK becomes overly used and misused. This article outlines the process to correctly use and understand the limitations of vulnerability data within each

level of the Hierarchy of Survivability pyramid. In order to highlight the modeling limitations and data flow, a new vulnerability related term is developed for each level of the analysis pyramid.

PARAMETRIC TESTS AND ENGINEERING ANALYSIS

Starting at the base of the pyramid, parametric tests and engineering analyses are completed. Joint Live Fire and Live Fire Test programs use high fidelity test articles and computer simulations, such as WINFIRE, are used to determine the probability of defeat for a bare component being impacted with a single fragment (or projectile). Within the last few years this term has been called probability of component dysfunction given a hit (PCD/H). A more complete description is the single shot, bare component probability of dysfunction given a hit (PSSBCD/H). The term "single shot" implies no coupling between shotlines that could result in synergistic or cascading effects from multiple impacts. The phrase "bare component" highlights the component is not installed into the aircraft configuration. The term "dysfunction" clarifies that component damage is acceptable if the component still performs the required function. The PSSBCD/H data is a function of the failure mechanism. Aircraft have numerous failure mechanisms. The following list highlights a few of the major failure mechanisms: 1) explosion in the fuel tank ullage (air space above the fuel); 2) hydrodynamic ram damage to structural members; 3) fire damage to critical equipment; 4) loss of functional capability (i.e., flight controls, propulsion system); and 5) crew casualties.

VULNERABILITY ANALYSIS

The vulnerability analysis level investigates an aircraft capability against a single shot fragment (projectile). The vulnerability of an aircraft is expressed as vulnerable area (AV) and is measured in square feet. The vulnerable area, A_v , of a target is defined to be:

$$AV = AP \int \int p(x,y) dx dy$$

where $p(x,y)$ is the probability that the target is defeated by an impact of a single

Mr. Griffis received his B.S. in Systems Engineering at Washington State University in 1981. He has been serving as the JSF lead for vulnerability reduction and Live Fire Test & Evaluation since Dec 1997. Mr. Griffis is the 1996 recipient of the American Defense Preparedness Association Combat Survivability Technical Award. He is senior engineer guiding the AFRL/VAV, YDI, XRA and contractor team and in Jan 98 became the model manager for FASTGEN4 and COVART4. He may be reached at 937-255-4358.

▼ Figure 1.
Hierarchy of
Survivability

projectile at the point (x,y) for a given attack orientation. The presented area (A_p) of the target is projected into this attack orientation. AV is a function of the critical component, threat attack orientation, impact speed, fragment (projectile) size, and threat type.

A wide range of threat types such as a missile fragment, a High Explosive Incendiary (HEI) projectile, and an Armor Piercing Incendiary (API) projectile can be modeled.

Computer programs typically used by ASC/XRA are COVART4 and FASTGEN4. The COVART4 model uses expert rules, empirical equations, test data (such as warhead threat characterization data and PSSBCD/H data) and the FASTGEN4 model uses a detail target description of the aircraft.

The detail target description of the aircraft includes critical components and non-mission critical components. Non-mission critical components are included within target description, because they shield or mask the critical components from the fragment (projectile). The location and quantity of shielding is calculated by tracing (ray tracing) the fragment (projectile) trajectory through the aircraft target description. A fragment (projectile) path through the target description is called a shotline. FASTGEN4 generates multiple independent shotlines within a grid system for a given attack orientation.

COVART4 determines when a single

path intersects multiple critical components which have the same function. The description of the interrelationship of critical components and functions is called a fault tree. A multiple function (pitch, yaw, and roll) fault tree of the flight control components enables the analysts to assess the vulnerable area related to each function. The flight control functional failures may include mechanical, hydraulic, and electrical systems. Other failure mechanisms, such as sustained fire may occur by damaging a single component. These types of components are called singularly vulnerable components.

Modeling of High Explosive Incendiary (HEI) projectiles includes multiple fragments from one burst point. HEI analyses do account for multiple functional failures, via the COVART4 fault tree capabilities. Endgame analyses account for multiple fragment impacts from missile fragments.

COVART4 can indirectly model cascading and synergistic effects (i.e. hydrodynamic ram). Hydrodynamic ram sensitive components are modeled by defining an allowable distance from the critical structural element. That element is assigned a PCD/H. A similar approach can be used to model engine fuel ingestion that results in a fire or explosion.

COVART4 generates component vulnerable area (AV) or probability of kill (PK) data. A more accurate description of the PK term is the single shot, shielded component probability of dysfunction given a hit (PSSSCD/H). The term "single shot"



shot can defeat redundant shielded components. Redundant components can be defeated if a single fragment's (projectile's)

implies no coupling between shotlines.

ONE-ON-ONE FLYOUT ANALYSIS

The one-on-one flyout level analysis determines the geometric relationship between threat and target. These analyses are critical to determining aircraft survivability because they determine the missile warhead trajectory, body axis, and burst point (velocity and position relative to the aircraft). Computer programs typically used by ASC/XRA are ESAMS2.8 and MOSAIC.

These flyout analyses determine how a surface to air missile (SAM) or Air to Air Missile (AAM) engages a target aircraft. ESAMS/MOSIAC determines if and how far away the SAM site detects, acquires, and tracks the aircraft. This part of the modeling hierarchy captures the site's capabilities versus the aircraft's RF/IR signature, altitude, and speed. The combination of these factors can be expressed in terms of the probability of missile launch given engagement PL/E.

Given a launch, ESAMS/MOSAIC determines if and how the missile detects, acquires, tracks, and fuzes on the target aircraft. This portion of the one-on-one flyout modeling keys upon the aircraft's near field signature, electronic combat capabilities, and tactics/maneuverability versus the missiles capabilities to track and approach the aircraft. This set of factors can be expressed in terms of the probability of fuzing given a launch PF/L.

A continuous set of aircraft positions about the SAM site (offsets, up/down ranges, altitudes, speeds) are possible. Each aircraft position results in a specific missile flyout. These aircraft positions are parametrically located within a polar or rectangular grid, centered about the SAM site. A plot of this grid is called a footprint. The PL/E and PF/L footprints provide valuable insight about the site, missile, and aircraft capabilities.

ENDGAME ANALYSIS

The next level of the pyramid is endgame - terminal effects. The endgame - terminal effect analysis determines if the aircraft survives the missile launch. The computer program typically used at ASC/XRA is SHAZAM2. The terminal effects analysis accounts for three potential kill mechanisms: 1) the missile directly impacting the aircraft; 2) missile detonation inducing blast structural damage; and

3) missile fragments impacting the aircraft. Currently used methodologies to predict failure due to direct impact and blast kill mechanisms lacks robustness; however, these methodology do adequately capture first order effects.

The missile fragment impact locations are based upon arena warhead characterization tests. The actual fragment impact location is unknowable; however, the fragment pattern (fragment maximum and minimum impact angles, velocity, and weight) can be predicted via a Monte Carlo simulation. If multiple fragments strike a component, the Survival Rule equation is used to determine the component kill. The product of each component probability of kill results in the target probability of kill given fuzing (PTK/F):

$$PTK/F = 1 - [(1 - PSSCD/H)A1 (1 - PSSCD/H)B2 \dots (1 - PSSCD/H)ZN],$$

where A,B...Z equals the number of impacts on a specific component and N is the Nth component hit. If a fragment impacts a redundant component, the fault tree is evaluated prior to determining the PTK/F.

The endgame - terminal effect analysis uses the vulnerability analyses single shot, shielded component, probability of dysfunction given a hit data. As with HEI analysis, the methodology does not explicitly account for unique failure mechanisms from multiple fragment impacts in a close proximity (i.e. removal of structure due to fragment induced cracks from adjacent fragment impacts). However, the model does account for multiple impacts and functional failures, via the fault tree capabilities. Cascading and synergistic effects are indirectly modeled with fault tree capabilities.

Figure 2 shows a missile engaging an aircraft where the warhead has detonated and warhead fragments have flown behind the aircraft without hitting the aircraft. An endgame model, when given the missile/aircraft kinematics and the missile detonation point, can calculate the fragmentation pattern using the velocity vector to determine if fragments impact the target aircraft. Using simplifying concepts, such as lethal radius, are not preferred and may be misleading. An endgame model (i.e. SHAZAM2) that uses the kinematics of the

terminal conditions better reflects the solution than lethal radius.

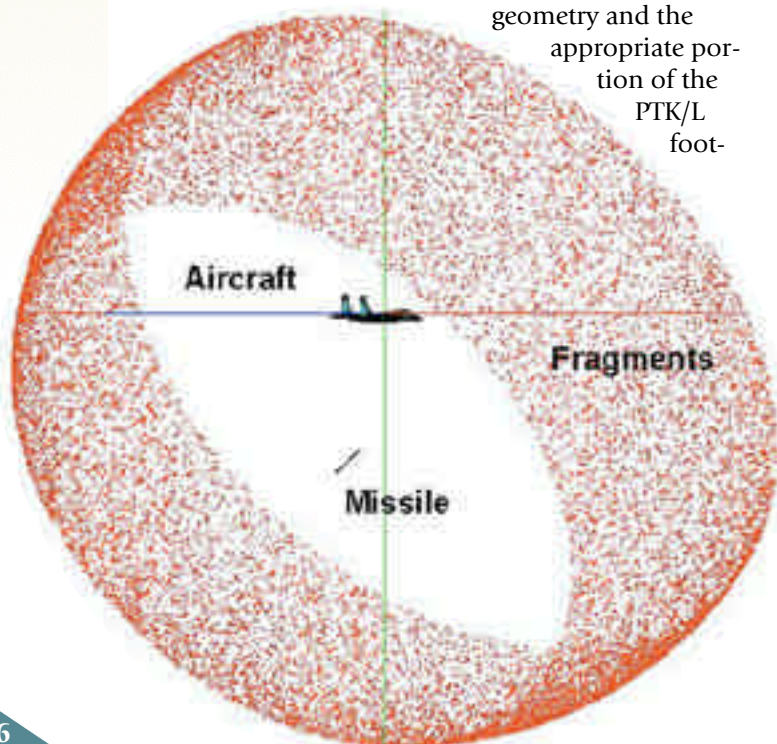
The combination of the one-on-one flyout and endgame - terminal effect modeling are expressed in terms of the probability of target kill given a launch (PTK/L).

$$\begin{aligned} \text{PTK/L} &= \text{Flyout} \times \text{Endgame} \\ \text{PTK/L} &= \text{PF/L} \times \text{PTK/F} \end{aligned}$$

MISSION ANALYSIS

The subsequent level of the pyramid is mission analysis. This level determines an aircraft's capability to survive in a combat scenario. The mission level model used by ASC/XRA is Suppressor. Mission analysis captures the effects of a strike force package, with escort and standoff support assets, attacking an integrated air defense system (IADS) laid out within a specific geographic region. The strike force package includes mission planning incorporating threat avoidance while still being able to attack assigned targets, lethal and non-lethal SEAD and on board assets. All key components of the integrated air defense system are considered. These components include operations centers, radar posts and the lethal response of the threat including SAM brigades, battalions and fire units as well as autonomous fire units.

The capabilities of the modeled threat IADS determines when and if a site launches a weapon. The missile flyout times, firing logic and site assessment logic determines the missile launch attack geometry and the appropriate portion of the PTK/L footprint.



print. This footprint is from the one-on-one analysis after processing the terminal conditions through endgame analysis. Mission analysis determines the expected number and type of weapon launches during a variety of missions and threat conditions against all systems in the combat scenario.

CAMPAIGN ANALYSIS

The ensuing level of the pyramid is campaign analysis. The campaign analysis level determines the capability of multiple systems to prosecute the war. The campaign level model used by ASC/XRA is THUNDER. The THUNDER model plays both the BLUE and RED sides; and both sides react to the opposite side's activities. The THUNDER model captures many effects; however, these effects are treated with less fidelity. Therefore, prior to completing production runs, the analysts must calibrate the THUNDER database. This calibration process is accomplished such that the number of THUNDER encounters statistically equals the number of encounters and PTK/L obtained with the Suppressor mission analysis.

The SAM launch radius published within intelligent reports should not be used within THUNDER. The published data are based upon the missile's kinematic range and a few aircraft altitudes and speeds. Mission calibration studies should be completed for the class of terrain that reflects the region where the war is occurring. Additionally, the mission analysis determines the likely launch range based upon the threat IADS.

The campaign model uses launch radius and other parameters to trigger the firing logic. The mission analysis determines a statistical distribution of likely and realistic launches. These mission calibration studies obtain realistic launch conditions, the likely number of launches, and the likely probability of aircraft kill per launch.

SUMMARY

The Hierarchy of Survivability pyramid analysis process described within this paper is based upon the experiences of hundreds of person years at ASC/XRA. This capability has advanced and matured into an understandable and definable process. By using this process, important interactions such as vulnerability impacts on sortie generation are captured.

▼ Figure 2.
Missile
Engagement

The views expressed in the following article are those of the author and not necessarily those of the Central Intelligence Agency.

Several new threats that have emerged since the end of the Cold War pose new challenges to government and industry. The capabilities and level of technology of advanced conventional weapons has risen dramatically over the past 5 years. This trend will likely continue for at least the next decade. The potential use of man-portable surface-to-air missiles (SAM) by terrorists is an issue that has received renewed interest since the TWA-800 tragedy.

The proliferation of advanced conventional weapons with capabilities comparable to and in some cases better than, their U.S. counterparts is of significant concern. Modern air-to-air missile systems, including advanced dogfight missiles coupled with helmet-mounted sights are available on the arms market today. Air-to-air missiles may also be under development with ranges that make them a significant stand-off threat to reconnaissance and surveillance aircraft.

Modern infrared (IR) air-to-air missiles are now capable of locking onto aircraft at off-boresight angles approaching 90 degrees. Lock-on after launch seekers are also being pursued to provide an "over-the-shoulder" engagement capability. These advanced IR air-to-air missiles will rely on a helmet-mounted targeting system, which simplifies the seeker cueing and overall engagement process. These systems may even compensate for deficiencies in pilot training and proficiency. Several advanced dogfight missile systems are more advanced than any now fielded by the United States.

France and Russia have considered the development of a new class of air-to-air missiles with ranges in excess of 300 km. The expressed purpose of these weapons is to counter standoff reconnaissance and surveillance aircraft. The ability of such systems as the U.S. AWACS and JSTARS to act as force multipliers was vividly illustrated during DESERT STORM. Ensuring the survivability of these high-value assets is key to future U.S. force deployments.

The number of man-portable SAMs under development and the number of SAM developers has increased over the past decade. In addition, these systems have been proliferated in more than 100 nations in every region of the world. A majority of man-portable SAMs in service worldwide are older generation systems that are susceptible to simple flares or IR jamming systems. However, the newer systems under development are significantly more capable and resistant to all but the most advanced IR countermeasure systems. Therefore, any attempt to quantify the threat posed by these weapons should weigh the system's performance and its current and future proliferation.

The TWA-800 tragedy brought renewed focus to the issue of terrorist use of man-portable missiles. The ease with which these systems can be concealed and operated makes the employment of these weapons attractive to terrorists. Although civilian aircraft typically fly at altitudes well above the reach of these systems, the aircraft are susceptible during takeoff and landing at ranges of more than 70 km from the airport. Because most of this area is outside the control of airport security, reducing the vulnerability of civilian aircraft to these weapons may be prudent. This presents an excellent opportunity for the U.S. military and defense industries to share vulnerability reduction and countermeasure technologies with the civilian sector.

Mr. Jolley is the Director of the Vulnerability Reduction Sub-group, the Army Civilian representative to the Central Office and was recently appointed Director of the Central Office in January 1998. He may be reached at 703-607-3509.

▼ Left to Right: Mr. Ralph Lauzze (AFRL), Professor Robert Ball (NPS) and Mr. Hardy Tyson (China Lake)

JTCG/AS Goes "On The Record" At TWA 800 Crash Hearing

by Mr. Joseph P. Jolley

The existence and purpose of the JTCG/AS is now part of the public record as a result of expert testimony given during the recent National Transportation Safety Board (NTSB) Investigative Hearing into the crash of TWA Flight 800, which occurred July 17, 1996. The hearing was open to the public and held in the Baltimore, Maryland Convention Center, from December 8 to 12, 1997.

As shown on C-Span, which covered the event daily, the three panels on an elevated platform under the glare of television lights were, the Board of Inquiry in the center, chaired by Mr. Jim Hall, Chairman of the NTSB; the Technical Panel on the left composed of NTSB Investigators; and the Expert Witness panel on the right.

Immediately in front of the three panels were the Parties to the Hearing, which are provided for by the Safety Board rules. It is comprised of "those persons, governmental agencies, companies, and associations whose participation in the hearing is deemed necessary to the public interest and whose special knowledge will contribute to the development of pertinent evidence." The Parties to the Hearing, numbered about 60 people, included representatives from the Federal Aviation Administration (FAA), the Airline Pilots Association (ALPA), Trans World Airlines (TWA), The Boeing Company, the Interna-

The purpose of the hearing, as stated by Mr. Hall, in his opening remarks was "for the purpose of supplementing the facts, conditions, and circumstances discovered during the on-scene investigation. This process will assist the Safety Board in determining the probable cause and in making any recommendations to prevent similar accidents."

Additionally, according to Mr. Hall, there were two goals of the aircraft accident investigation: determine the ignition source that sparked the fuel tank explosion, and find the best means to reduce the likelihood of explosive fuel and air vapors from accumulating in airliner fuel tanks. In working to achieve these goals, the hearing received sworn testimony from nearly 50 expert witnesses in the following areas:

- Examination of cockpit voice recorder, flight data recorder, and radar data, and sequencing of breakup
- Fuel tank design philosophy and certification standards
- Flammability of Jet-A fuel
- Ignition sources
- Aging aircraft
- Flammability reduction

Nine of the expert witnesses were from the DoD: five from the Air Force and four from the Navy. The aircraft combat survivability community was well represented with four of the best "experts" available to answer questions and contribute valuable information. From the Navy was Distinguished Professor Robert Ball of the Naval Postgraduate School at Monterey, California, and Mr. Hardy Tyson and Mr. Richard Bott from the Survivability and Lethality Division at China Lake, California. The Air Force was represented by Mr. Ralph Lauzze from the Air Force Research Laboratory at Wright-Patterson Air Force Base, Ohio, who is also Chairman of the JTCG/AS. All of these gentlemen were witnesses on the Flammability Reduction Panel, except for Mr. Bott who was a member of the panel that examined flight data and the sequence of breakup.



tional Association of Machinists and Aerospace Workers, Honeywell, and Crane Company/Hydro-Aire.

The Flammability Reduction Panel was last on the docket to give testimony during the 5 days of hearings. A purpose of this subject area was to hear from the military on technologies and techniques used to protect combat aircraft from fuel tank explosions. The hearing format called for questioning the expert witnesses by the Technical Panel, followed by questions from the Parties to the Hearing, and finally the Board of Inquiry. During the proceeding, Board of Inquiry members could interject questions (and frequently did) at any time.

Questioning of the Flammability Reduction Panel began the afternoon of December 11, 1997, with Professor Ball “holding class” in Survivability 101. Professor Ball presented a comprehensive overview of the facts and history of combat survivability. He identified the JTCCG/AS, explained how it began, and described its role in the survivability community. He also covered the Live Fire Test law and the Joint Live Fire program. He described the overlap between survivability and system safety; listed fuel tank fire and explosion prevention techniques such as foam, nitrogen inerting, halon 1301, and ullage venting; and showed a slide of current military fighter and cargo aircraft with fire suppression systems installed.

Mr. Hardy Tyson next explained the kinds of vulnerability testing conducted at China Lake. There are active dry bay fire suppression systems installed in Navy aircraft, but no active ullage explosion suppression systems are installed in Navy aircraft. Foam and On board Inert Gas Generation System (OBIGGS), which are used by Navy aircraft for ullage explosion suppression, are passive. Mr. Tyson described the OBIGGS system and the use of foam as vulnerability reduction techniques and answered questions. He also passed samples of the foam used in aircraft fuel tanks for inspection of the Board members.

Mr. Lauzze presented an overview of fire and explosion suppression techniques used in Air Force aircraft. He showed a slide of an A-10 aircraft with a large section of upper wing skin missing, which was attributed to enemy fire. The aircraft was able to land safely partly because the on board fire suppression system worked properly. Mr. Lauzze also discussed alternatives to Halon 1301 and the selection of HFC-125 as a short-term solution and the

DoD Next Generation Program that is working on a long range solution. Mr. Lauzze was quoted in the October 12, 1997 USA Today stating that “foam works.”

Questioning by the NTSB Technical Panel then turned to the remaining panel members. Questions to Mr. McSweeney from the FAA continued for more than 1 hour. Questions focused on the history of what consideration the FAA had historically given to the military options for fire suppression. Mr. McSweeney stated that most research conducted in the 1960s was to protect against post-crash fires. Anti-misting fuel tests that were conducted then, failed. Foam was considered but rejected because it did not provide enough safety improvement, according to Mr. McSweeney. He further stated the FAA was working with the military to help solve problems, but offered no details.

Considerable discussion followed regarding the immediate safety benefit to be derived from transitioning to JP-5 fuel from Jet-A, on commercial aircraft. Issues to be addressed include the need to increase the supply of JP-5 and whether the price difference between the two fuels is a problem. Mr. McSweeney said the FAA is looking into the JP-5 possibility. He indicated that the American Petroleum Institute, along with corporate leaders, are being consulted on the issue of converting Jet-A production to JP-5, a fuel with a significantly higher flash point than Jet-A. An FAA press release, dated December 19, 1997, states the FAA will also work with the Navy to learn more about the properties of JP-5 and its operational use.

In addition, the FAA has activated the Aviation Rulemaking Advisory Committee (ARAC) to begin a 6-month study to develop a list of specific solutions for the overall problem of reducing the vulnerability of aircraft fuel tanks to the potential for fire and explosion, for existing aircraft and new designs. Mr. McSweeney stated the military would be invited to the ARAC working board meetings.

The NTSB’s interest in improving aviation safety in the area of fire and explosion protection, is reflected in its “Most Wanted Transportation Safety Improvements” list published in May 1997 (copies available from the JTCCG/AS Central Office or the NTSB). Two of the eight improvements



that address aviation matters exclusively, deal with protection against the threat of fire and explosion. Those two improvements are to “require preclusion of operation of transport category aircraft with explosive fuel-air mixture in fuel tanks,” and to, “require the installation of fire detection and suppression equipment in airplane cargo compartments.”

The most significant result of the hearing was recognition of a shift by the FAA toward adopting a two-track approach to design of commercial aircraft fuel systems and fuel tanks and for solving related safety problems on in-service aircraft. According to the NTSB, this change is also a move to a position previously advocated by the NTSB. According to published information, aircraft designers now use a “one-track” approach in fuel tank design, which focuses on eliminating any ignition source from inside the tank. The two-track approach requires the design also address stabilizing the fuel tank vapors in addition to eliminating ignition sources.

Solving the tragedy of TWA Flight 800, so that such a disaster will not be repeated, may provide a special opportunity for the military combat survivability community to contribute its unique kind of expertise, in the search for the right solution(s). From the week of hearings, the NTSB appeared sincerely interested in cul-

tivating the civil and military relationship and energizing it to the maximum extent possible, and to take advantage of the body of knowledge already available that concerns aircraft fuel tank fire and explosion hazards.

The framework for a cooperative relationship already exists in the form of a memorandum of agreement (MOA) between the JTCG/AS and FAA. The MOA, which has been in effect since March 28, 1994, facilitates the sharing of data, “for use in enhancing the survivability and/or safety of existing and future commercial aircraft.” The agreement was not intended to take precedence over any other agreements between elements of the DoD and FAA.

After 5 days of hearings, on December 12, Mr. Hall declared the hearing recessed indefinitely. The investigation continues, however, and the hearing could be reconvened if necessary. These public hearings, which were the largest and most costly of any in the NTSB’s 30-year history, were undertaken as part of the largest investigation of a transportation accident in our nation’s history. The NTSB web site (www.nts.gov) provides exhibits, a witness list, and biographical information on all members of the Board of Inquiry and the Technical Panel, as well as general information.

ALTERNATIVES TO HALON: A STATUS REPORT

by Mr. Mathias L. Kolleck

The Clean Air Act Amendments (CAAA) of 1990 and U.S. Environmental Protection Agency (EPA) rules limit U.S. consumption and production of ozone depleting substances (ODS). These actions carry out the United States' obligations under the "Montreal Protocol on Substances that Deplete the Ozone Layer," an international treaty ratified by the Senate in December 1988, limiting global production and consumption of such chemicals. Subsequent international and national legislation has dictated the phaseout of the production of such chemicals. In response, industry producers have ceased production as of January 1994. These restrictions were put in place because of data showing the atmospheric chlorine loading caused by these chemicals depletes the earth's protective stratospheric ozone layer.

Some of the most important of the ODS chemicals are the halons, especially Halon 1301. CF₃Br Halons are important because they are used as the primary fire-extinguishing chemical for all aviation use, including military and commercial aircraft and have been used since the late 1940s. After many years of operational experience, Halon 1301 emerged as the favored agent for aircraft primarily because of the wide range of applications to which it is suited.

A decision was made by the U.S. Air Force in 1992 to develop a "nonozone depleting solution" for on-board aircraft fire extinguishing by 1995. To meet this objective, a three-phase program for evaluating and identifying alternative extinguishing agents that would be commercially available was developed by the Air Force's Wright Laboratory. The Halon Replacement Program for Aviation was subsequently expanded in scope to include the requirements of all U.S. military and commercial aircraft applications and was jointly sponsored by the U.S. Air Force, Navy, Army, and Federal Aviation Administration. This program was completed in 1995. Also in 1995, the Navy completed a test program using the F/A-18 E/F and Solid Propellant Gas Generator (SPGG).

In addition to the Halon Replacement Program for Aviation, other ongoing or recently completed programs are addressing this issue. Wright Laboratory is engaged in an effort with the F-22 System

Program Office (SPO). A program utilizing solid propellant gas generator (SPGG) technology has recently been completed. This program examined the engine nacelle. Another test series investigating the effectiveness of SPGG technology in F-22 dry bays began in January 1998.

Each of the programs mentioned previously was initiated to find a near-term solution to the halon replacement requirement. Longer term solutions will be developed under the Next Generation Fire Suppressant Technology Program (NGP). This program is being headed by Dr. Richard Gann at the National Institute of Standards and Technology (NIST). The goal of this program is to develop effective and environmentally friendly fire suppression techniques by the year 2004.

A considerable amount of resources has been, and continues to be, devoted to the issue of fire suppression. Is it worth it? How big of a problem is fire and subsequent fire damage? SURVIAC personnel have conducted a study to estimate these costs. The results of this study have estimated the costs of fire and fire protection to the United States Air Force to have been \$15.465 billion from 1966 to 1995 (measured in 1995 dollars). Costs that were included in this estimate are peacetime losses, combat losses, and costs of research and development. Projected costs for the period 1996 to 2025 are \$15.990 billion (measured in 1996 dollars).

What about the benefits of fire protection? Using the cost data mentioned above, a net present value of \$119 million was estimated for the 1996 - 2025 time period. This amount is probably understated as more expensive aircraft enter the inventory. A study conducted by the Aeronautical Systems Center (ASC) Safety Office calculated the benefits of fire protection to be \$706 million over a 25-year period.

In summary, fires are costly events. Furthermore, the restrictions on halons will only grow worse. There is some sentiment among various nations of the world to ban the use and production of halon. The recommended replacement is HFC-125, with programs under way to develop a long-term solution to this serious problem.

Mr. Kolleck is a senior associate with Booz·Allen & Hamilton. He has 12 years experience as a Survivability/Vulnerability Engineer. For the past five years, he has been supporting the Joint DoD/FAA Halon Replacement Program for Aviation. Mr. Kolleck earned his B.S. in Aerospace Engineering from the University of Cincinnati and his M.B.A. in Finance and M.S. in Economics from Wright State University. He may be reached at 937-431-2700.

Calendar of Events

Event	Date	Location	POC
Aircraft Fire Hazards	17-18 Mar 98	Woburn, MA	BlazeTech Corp. 617-661-0700
Explosions and Fuel Tank Fires in Aircraft	18-19 Mar 98	Woburn, MA	BlazeTech Corp. 617-661-0700
Vulnerability Reduction Subgroup Meeting	7-9 Apr 98	Arlington, VA	Joe Jolley 703-607-3509 ext. 14
Integrated Survivability Assessment Workshop (Mission Level Models)	21-22 Apr 98	Colorado Springs, CO	Maj. Richard Lockwood 703-607-3509 ext. 17
Survivability Methodology Subgroup Meeting	23-24 Apr 98	Colorado Springs, CO	Maj. Richard Lockwood 703-607-3509 ext. 17
43rd Annual Joint Electronic Warfare Conference	27-30 Apr 98	Colorado Springs, CO	Mr. Douglas Buse 937-255-0262 ext. 3834
Aircraft Combat Survivability Short Course	27 Apr - 1 May 98	Monterey, CA	Alice Roberson 408-656-2426
36th I.R.I.S. Symposium on IRCM	4-8 May 98	Eglin AFB	ERIM Int'l Inc. 313-994-1200 ext. 2323
Aircraft Fire Protection & Mishap Investigation	3-7 Aug 98	Dayton, OH	AFP Associates Inc. 937-435-8778

Information for inclusion in the Calendar of Events may be sent to: SURVIAC, Washington Satellite Office,
8283 Greensboro Dr., Allen 663D, McLean, VA 22102, Attn: Christina Wright 703-902-3176, FAX 703-902-3425.

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